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GEOLOGICAL MAGAZINE

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A Search for the Alleged Sinemurian in the Wadi Araba, Eastern Desert of Egypt

By W. J. ARKELL

ABSTRACT

Marine Lower Lias, with *Ammonites bucklandi* and other fossils, was recorded in the Wadi Araba by Figari Bey in 1864. No one has since been able to find marine Lias in Egypt, but in 1915 Greco figured a Sinemurian faunule, including an *Arnioceras*, from the Figari Egyptian collections at Florence, and claimed that Figari's discovery was confirmed. A special search for the locality was made in 1951, without success. The paper reviews the evidence and records Carboniferous rocks and fossils that were found. Some general remarks are also made on the structure and origin of the Wadi Araba.

I. HISTORY

IN his book of travels, Figari Bey, who was Professor of Natural History at the Medical School at Cairo, recorded the finding of Lias with *Gryphaea arcuata* and other fossils at three places in or near the Wadi Araba : namely, at Wadi Murakhan and Wadi der-Bakit, near St. Antony's monastery, and Wadi Azahal, near St. Paul's monastery (Figari, 1864, vol. 1, pp. 62–3, 142–3, and footnote on p. 51). At the first locality, Wadi Murakhan or Morakhan, he also recorded *Ammonites bucklandi.*

No one else has succeeded in finding marine Lias in Egypt. Greco (1915 and 1916, p. 105), however, stated that in studying Figari's collections of Cretaceous fossils from Egypt, presented to the Geological Institute at Florence in 1868, he came across a single specimen of *Arnioceras mendax* Fucini, together with *Gryphaea arcuata* Lam., *Chlamys* ? *textoria* (Schloth.), and two new species of Jurassic Rhynchonellids ; and he asserted that these fossils proved that Figari had discovered marine Sinemurian in the Eastern Desert. Greco concluded that the *Arnioceras* was the specimen recorded as *Ammonites bucklandi* and assumed that the locality, called by Figari Wadi Murakhan, was " Wadi Am Rockam, a short distance from the Monastery of St. Antony ". He could not find any fossils indicative of Lias from the other two localities mentioned by Figari.

Fourtau (1904, pp. 240–2) had described the Wadi Am Rockam and illustrated it with a geological section which shows it as running from south to north, off the north face of the South Galala Plateau into the Wadi Araba. He called it a branch of the Wadi Abu Hamat, and in it he found a quarry in black " marble " (i.e. limestone) worked by

Figari. From marl partings interbedded with the black limestone he collected a rich, well-preserved faunule of Campanian age, including *Baculites anceps* (*B. vertebralis* Lam., teste Greco, 1916, p. 114), overlain by the Maestrichtian beds with *Exogyra overwegi*. The lowest beds exposed in Wadi Am Rockam, according to Fourtau's findings, are whitish limestones with *Ostrea* cf. *dichotoma*, also Campanian. Nor does anything earlier than Campanian crop out at the Monastery of St. Antony, where Schweinfurth's *Schneeweisserkalk*, full of *Gryphaea vesicularis*, is still worked in the monks' quarry. Fourtau called attention to its striking similarity to Sinemurian limestones with *Gryphaea arcuata*, as found in Europe.

Sadek (1925 ; and 1926, p. 34), in reviewing the Jurassic of Egypt, considered Figari's Sinemurian unproven and in need of reinvestigation.

In 1948 Carpentier and Farag described a flora of probably Rhaetic-Infraliassic age from the north-east foot of the North Galala Plateau, beneath the marine Bathonian beds described by Sadek (1926, p. 35), and with no marine beds in between.

II. Appraisal of Evidence

Owing to the palaeogeographic importance of establishing the presence or absence of marine Sinemurian in Egypt, I corresponded during 1949 and 1950 with everyone likely to have visited the Wadi Araba or likely to be able to throw any light on the matter. For answering my inquiries I am grateful to the late Dr. W. F. Hume and Mr. O. H. Little, both formerly Directors of the Geological Survey of Egypt ; Professor M. M. Ibrahim, of Cairo University ; Mr. Gerald Andrew, Sudan Government Geologist and formerly of Cairo University ; Dr. Jean Cuvillier, also formerly of Cairo University ; and Mr. G. W. Murray, formerly Director and now Adviser, Topographical Survey of Egypt.

The majority opinion, expressed by Dr. Hume, was that floods which occurred in the cellars of the museum at Florence (as recorded by Greco) may have disarranged Figari's collections and mixed his labels ; though Mr. Andrew pointed out that " there is no inherent improbability of Sinemurian fossils turning up in the Nubian Series : it must be full of non-sequences, and one can always expect a ' missing ' horizon to turn up in the form of a fossil band. The search for fossils in the Nubian Series has been enthusiastic but far from thorough ".

The mixing of labels owing to floods did not seem to account for the facts that Figari, in his book, had recorded a Sinemurian ammonite and *Gryphaea arcuata* from a definite locality, before the fossils went to Florence, and that fifty years later Greco had found these fossils in Figari's Egyptian collection.

Mr. G. W. Murray pointed out that the Wadi Araba and its northern

tributaries, with the North Galala Plateau, had been mapped topographically and published in 1935 on the 1 : 100,000 scale (Sheet 4, Zafarana ; then unknown to me, because not in Cambridge University Library map room), and that two of the *northern* tributaries, flowing southwards into Wadi Araba opposite St. Antony, from the North Galala Plateau, are shown on the map as Wadi Abu Marakh and Wadi Bikheit. These Murray identified with Figari's Wadi Murakhan and Wadi der-Bakit, and he suggested that a Wadi " Uldahal " or el-Zahal, near St. Paul, might be Figari's Wadi Azahal, near St. Paul.

This suggestion threw an entirely new light on the problem, for everyone hitherto had assumed that Figari's locality for the *A. bucklandi* was on the *south* side of Wadi Araba ; moreover, Wadi Abu Marakh seemed much more likely to be Figari's Wadi Murakhan (*marakh* being a wadi plant) than Wadi Am Rockam (*rockam*, marble) ; and the proximity to Wadi Bikheit seemed to clinch the matter. Both these wadis open *towards* St. Antony.

Figari gave a detailed description of the occurrence in Wadi Murakhan. The following is a translation from the copy in the British Museum (Natural History) :—

" Towards (*verso*) the monastery of St. Antony the hermit, at the mouth of the valley called Wadi Morakhan, appears a group of compact black limestones, with bedding in high relief, which at first sight have the strongest resemblance to the Alpine Dolomite. This limestone changes in colour from black to ashen, then to dirty white. It contains fossils, and among others were noted *Plicatula spinosa* [1] in great abundance, *Ammonites bucklandi*, various *Ostrea*, *Gryphaea arcuata* ; and among the echinoids are *Diadema serialis*.[1] This group is raised at the S.E. and dips towards the N.W., accompanied conformably by a thick dyke [sill ?] [2] of granular basaltic rock of an olive-green colour, containing kidney inclusions of calcium carbonate in concentric layers and some veins of calcium sulphate and titaniferous iron.

" From what one can infer, this dyke [sill ?] has raised the said group of black Jurassic limestones of the Liassic epoch. Going up the valley of the Wadi Morakhan, the black limestone acquires a saccharoidal crystalline structure, and the ashen limestone passes into greyish white, which one might believe to be true dolomite. The basaltic rock accompanies it right to its head, and in fact ends by covering it entirely : towards the point of origin of the valley one no longer sees anything else showing but the stratification of the marls and green sandstones of the Lower Cretaceous " (Figari, 1864, vol. i, pp. 62–3).

The mention of a dip to the N.W. and the conspicuous igneous rock

[1] Greco did not find *Plicatula* or echinoids of Jurassic age in Figari's collections.

[2] " una grossa Dickes."

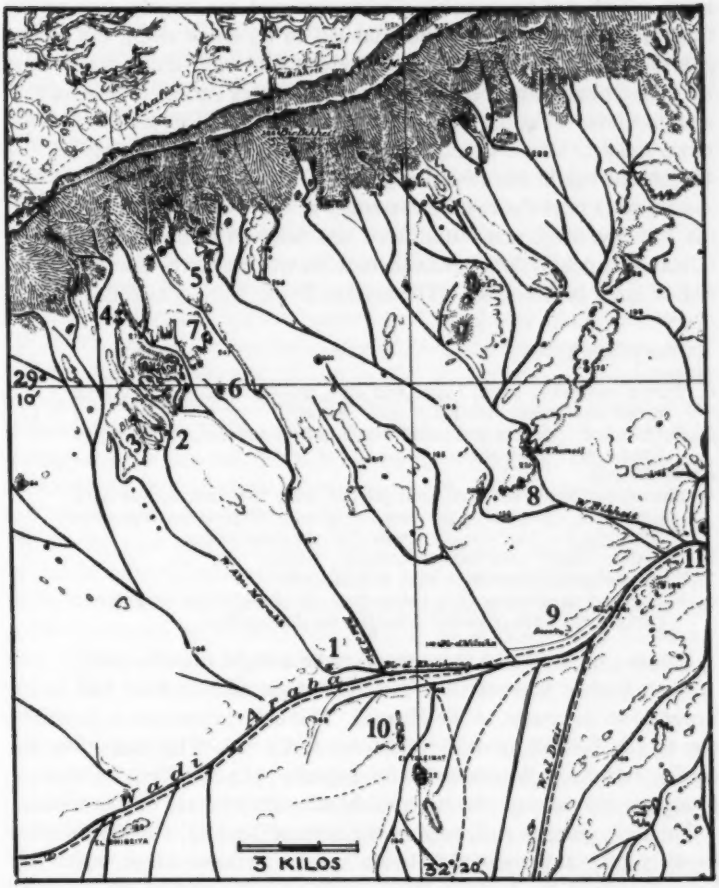
seemed to rule out the Wadi Am Rockam, where Fourtau found no igneous rock and where the dip is to the S.; and the description does not sound like a "marine intercalation" in Nubian Sandstone. All this seemed to support Murray's suggestion that the wadi was one lying north of the Wadi Araba, with its mouth opening south "towards" (*verso*) the monastery of St. Antony.

III. Investigations in January, 1951

I am greatly indebted to Mr. G. W. Murray for organizing an expedition and taking me for a five-day visit to the Wadi Araba and the other Jurassic outcrops under Khashm el Galala, and to Mr. Ibrahim 'Azzam, present Director of the Topographical Survey of Egypt, for providing the facilities. For the opportunity to take advantage of this handsome offer I am further indebted to the Egyptian Government, as whose guest I went to Egypt for a congress, 27th December–3rd January, 1951.

On 5th January we drove from the Wadi Sannûr down the Wadi Araba eastwards to the mouth of the Wadi Abu Marakh (see Text-fig. 1) and then turned up this wadi. For 7 kilometres the Wadi Abu Marakh is broad and shallow, the sides consisting entirely of Recent or Pleistocene gravels, except for a small exposure of Nubian Sandstone under the gravels on the east bank close to the mouth (1 on map). The wadi then enters a gorge through "black sandstone hills" as noted on the 1935 map. As it appeared that these hills were the only possible location for Figari's "mouth of the valley", we camped close to the opening of the gorge for three nights and investigated this and the neighbouring valleys. We found no igneous rock and no limestone that could by any stretch of imagination be likened to Alpine dolomite. The hills consist almost exclusively of sandstones and sands with sandy limestones containing abundant Carboniferous brachiopods. At the camp site (2 on map, Text-fig. 1) the section is as follows (thicknesses approximate, in metres) :—

		m.
10.	Sandstone or sandy limestone, brittle, brown, with small, smooth brachiopods and crinoid ossicles, passing down into sand. *Dielasma hastata* (Sow.), *Athyris ambigua* (Sow.), and *Athyris planosulcata* (Phillips), the last abundant	2–3
9.	Sandstone, hard	1
8.	Sandstone, soft, yellow, brown, and purple	7
7.	Sands, pale pink, yellow, and white, and soft nodular sandstone full of pseudopisolite (? manganese)	4
6.	Sandstone, false-bedded, yellow and brown	6
5.	Sandy limestone, hard, black, with poorly preserved *Spirifer*	½
4.	Shale, pale, soft, white, pink, yellow, and purple	5
3.	Sandstone, very hard, irregular	¼ to ¾
2.	Marls, mottled purple and pale green, veined with gypsum	1½
1.	Sandstone, buff, false-bedded; seen to	4
	Total, *c.*	32



TEXT-FIG. 1.—Part of the Zafarana sheet, Survey of Egypt (1935, sheet 4), showing part of the Wadi Araba and tributary wadis from the south scarp of the North Galala Plateau.

Farther west (3 on map) fossils in bed 5 ? are better preserved and we collected numerous fragmentary *Spirifer* cf. *convolutus* Phillips and *S.* aff *fasciger* Keys., and crinoid ossicles. Farther north, north of point 272 (4 on map) we collected from beds 5 and 10, the latter yielding numerous small *Athyris* and *Dielasma* (as above).

Crinoid ossicles were also collected at the top of the spur nearer the North Galala escarpment (5 on map).

The south-eastern boundary of these hills is a fault which throws down softer Nubian Sandstone, mainly purple and green loams or

clays, which are presumably Cretaceous and are largely covered by fan-gravel. An isolated pyramidal hill (6 on map) rising out of the gravel consists of these purple and green soft beds and contains near the base a remarkable pebble bed crowded with a variety of igneous and metamorphic rocks an inch and more in diameter, in addition to the usual quartz. Such a bed could account for "igneous gravels" of Pleistocene age in inconvenient places.

In a gully near the eastern extremity of the "black sandstone hills" (at 7 on the map) was found what was believed to be the junction of Cretaceous pebbly Nubian Sandstone on marine Carboniferous shales full of large brachiopods. The section in the gully is as follows :—

	m.
7. Pleistocene gravel	1
Nubian ?	
6. Purple sandrock, sand, loam, and clay, mottled and streaked pale green and white : coarse grains. About	13
5. Pebble bed : coarse sand and small quartz pebbles, none bigger than a pea. 3 inches.	
Carboniferous.	
4. Shales, yellow, green, red, and purple, with thin laminae of dark limestone crowded with large flattened *Orthotetes crenistria* (Phillips) (= *Derbyia* aff. *senilis* Phil. of Schellwien) . .	8
3. ? Shales. Gap ; soft beds, concealed ; about	3
2. Crinoidal sandy limestone with brachiopods	½
1. Shales and sandstones (big thickness). On loose slabs from some part of this were crowded *Chonetes hardrensis* Phil.	

Between beds 4 and 5 there seems to be a slight unconformity.[1]

Wadi Bikheit flows through a similar range of sandstone hills much lower down its course, at Bir Themeil. This escarpment also is probably due to a N.E.–S.W. fault, downthrown to the S.E. The sandstones are similar and dip N.W. under the fan-gravels. At point 8 on the map we found crinoid ossicles, which establishes that they too are Carboniferous.

The only igneous rock seen in the area of Text-fig. 1 is the peculiar small outcrop at 9, marked "Basalt" on the Zafarana sheet, which has been described by Andrew (1937, p. 9) as a "wall-like mass", and perhaps the filling of a fissure. It does not answer in any way to the occurrence described by Figari.

South of Wadi Araba we examined the group of hills at 10 on Text-fig. 1, near longitude 32° 20′ E. The most northerly part of the group comprises the nose of a N.E.–S.W. anticline, doubtless connected with the fault just alluded to, developed in Nubian purple clays, loams, and sandstones. Farther south are well-developed quartz pebble beds. Similar Nubian rocks crop out alongside the road to the monastery south of Text-fig. 1, near the south edge of the Zafarana sheet, where weathering of the pebble beds produces a quartz shingle.

[1] Figures of the Carboniferous fossils mentioned will be found in Walther (1890), Schellwien (1894), and Ball (1916).

It is, of course, still possible that Jurassic rocks may come in between the Carboniferous and Cretaceous somewhere along the foot of the south escarpment of the North Galala Plateau, although this could scarcely be the locality described by Figari as near the *mouth* of a wadi. The average height of the cliff is about 700 metres (2,300 ft.). At the foot is a labyrinth of steep wadis, inaccessible by car on account of the size of the boulders and the steep bounding walls ; but so far as could be seen the sections are mainly in slipped masses (as noted by Ball, 1910), scree, and enormous cones of " fanglomerate ".

On the other hand, observations by several geologists make it highly improbable that any marine Jurassic will be found south of latitude 29° 30′ N., that is, the northern edge of the Zafarana 1/100,000 sheet. Walther (1890, p. 448) records that in 1885 he climbed up a watercourse to Abu el Mesâd spring, which is presumably Bir Abu el Meisa of the Zafarana sheet, at 557 m. above sea, on the face of the North Galala escarpment just beyond the N.E. corner of Text-fig. 1. He measured a continuous section of sandstones and marls from the highest crinoid bed up to marls containing Cretaceous *Exogyrae* and ammonites. Mr. G. Andrew kindly informs me (*in lit.*) that in the winter 1932–3 he and M. Jean Cuvillier examined the foot of the scarp just east of Bir Bikheit and again up Rod el Hamal, farther east—that is, between the points examined by Murray and me and by Walther—and found no sign of Lias. They also searched for about 10 km. along the seaward end of the South Galala scarp, south of Bir Zafarana, with the same results.

Finally, on the seaward face of the North Galala Plateau, as far north as Wadi Abu Darag, which joins the coast at latitude 29° 29′ N., Cuvillier (1937) describes the Carboniferous with its usual brachiopods as again overlain by sandstones which extend up to the Cenomanian.[1] The marine Bathonian beds of Ras el Abd and Khashm el Galala must therefore wedge out quite suddenly southwards, in a distance of no more than 5 km.

IV. General Remarks on the Wadi Araba

The Carboniferous fossils found by us extend by a few kilometres north-westwards the outcrop of the Carboniferous system shown on the Geological Survey map of 1928, and bring it northward close under the Eocene scarp. Carboniferous fossils were first found in the Wadi Araba in 1883 by Schweinfurth, at the point marked 11 on Text-fig 1. At the same spot Schweinfurth and Walther camped in 1885 (see Walther, 1890, pl. xxiii).

Our observations confirm Ball's conclusion (1910) that the Wadi

[1] For reference to this paper I am indebted to Mr. G. Andrew.

Araba is a valley of erosion, and the outward dips at the bounding escarpments suggest that it is in the main anticlinal. Not only is the floor considerably folded and faulted, as described by Walther, however, but at the longitude of our observations the Carboniferous and Cretaceous sandstones dip gently inwards from both sides towards the centre, so that the internal structure of the valley is gently synclinal.

It seems possible that the initiation of this great erosion hollow, 50 miles long and 20 miles wide, was due to consequent drainage along a syncline between two parallel anticlines. The internal structure of the Gebel Maghara dome likewise reveals two parallel anticlines, but closer together (Moon and Sadek, 1921, pl. v). When the gravels of the east side of the Nile valley come to be mapped and investigated in detail it will be worth bearing in mind the possibility that the original consequent drainage of this pitching syncline may have been westward into the Nile valley, along the line of the lower Wadi Sannûr, the present Wadi Araba being a successful obsequent activated by the later stages of rift-faulting in the Gulf, and mainly due to spring action.

At present almost the whole floor of the middle and upper Wadi Araba, across its 20-mile width, is covered by flat sheets of fan-gravel, the spread-out debris from the limestone cliffs. Two flats predominate : the present surface and another about 50–60 feet higher, the two levels being usually separated by a cliff. There are places, however, where a relatively inactive wadi still fans out over the higher plateau, while a neighbouring wadi with larger catchment has cut down to the lower level, the two floors separated by nothing but a step. It does not follow, therefore, that higher gravel spreads are necessarily older than lower ; the depth to which any wadi or complex of wadis has cut into the general floor of the valley probably depends on the size of its catchment high up on the cliffs, and this may change from time to time as the cliffs recede.

V. Conclusion

Such is the handicap of negative evidence that it will be impossible to assert that no marine Lias exists in the Wadi Araba until a large area has been examined in detail. Nevertheless, one may form an opinion, and to this end it is worth while to recapitulate and arrange the relevant facts.

(1) The wedging out of the Egyptian Jurassic southward, both under the North Galala Plateau and under the Plateau of Tih, in Sinai, makes it improbable that marine Lias should occur some miles farther south. The improbability has been increased by the discovery of a terrestrial plant bed of about Rhaetic-Infra-Liassic age at Khashm el Galala, well to the north, which was in the direction of open sea in the Jurassic.

(2) It is clear from Figari's text that what he took for Lias is fairly

widespread in the Wadi Araba ; he recorded *Gryphaea arcuata* from all his three localities, near St. Paul as well as near St. Antony.

(3) There is in the Wadi Araba a formation which bears a striking resemblance to the European Lower Lias of the Bucklandi Zone : namely, the compact grey, black, and white Campanian limestone. It crops out at St. Antony and St. Paul and is full of *Gryphaea vesicularis*, which in size, shape, and colour strongly resembles *G. arcuata* of the Lias.

(4) Not all the fossils mentioned from the Lias by Figari were found by Greco in the collection ; and not all the Jurassic fossils found and figured by Greco were mentioned by Figari. In fact, the only two forms common to both are *Gryphaea arcuata* and the ammonite. Greco failed to find a *Plagiostoma* or a *Pleurotomaria*, both recorded by Figari, or any Jurassic echinoderms, or " *Plicatula spinosa* ", which had been said to be so common. Instead, he figured a Liassic *Chlamys* and two species of Rhynchonellids, none of which corresponds with anything mentioned by Figari.

(5) The Liassic faunule figured by Greco has a strongly European flavour. The *Arnioceras* is identifiable specifically and even varietally with an Italian form.

(6) Figari was familiar with the Wadi Araba and spent some time there, for he worked a " marble " quarry in the tributary Wadi Am Rockam and sank a shaft for coal in the Wadi Araba Carboniferous (which Murray and I saw and were told was called " The Dry Well ").

(7) The two wadis " towards the Monastery of St. Antony ", near the mouth of which Figari recorded Lias and which he called Wadi Murakhan and Wadi der-Bakit, agree in position and in name (considering the passage of a century) with the Wadi Abu Marakh and Wadi Bikheit.

(8) Both these wadis are cut entirely in Carboniferous rocks and Pleistocene or Recent gravels. Figari's description could not possibly have been drawn up in either of them.

The conclusion is that the valley described by Figari as Wadi Murakhan is not in Egypt at all but in Italy, and that some muddle over a notebook and a collecting bag was occasioned perhaps by failing memory and a conviction that the *Gryphaea* limestone of the Wadi Araba was Lias. If Figari's notebooks or journal ever come to light it will be interesting to see whether at any time he paid a visit to Tuscany to examine the Lower Lias for comparison with what he had found in Egypt, or whether he was sent Italian material by a colleague.

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Note on the Alleged Purbeckian at Murzuch, Fezzan, Libya

By W. J. Arkell

THE only fossiliferous representative of the Jurassic system reported to exist in Fezzan (Libya) is the thin freshwater limestone of Murzuch, which is supposed to be Purbeckian. Professor A. Desio (1938) first attributed this deposit to the Mesozoic and dubiously to the Cretaceous, but Pagni (1938) identified from it the Purbeckian gastropod *Valvata helicoides* Forbes and the Purbeckian plant *Chara jaccardi* Heer. On the strength of these determinations Professor Desio (1939, 1942) later stated that the Murzuch Limestone " should perhaps be referred to the lacustrine Upper Jurassic (Purbeckian) ". The gastropods, as shown in the figures by Pagni, however, do not resemble the true *Valvata helicoides* de Loriol ex Forbes MS. (refigured Arkell, 1941, p. 89, figs. 14 a, b, 60, 61, 62). During 1950 I pointed this out to Professor Desio. He kindly allows me to record that he was always doubtful about the age of the Murzuch Limestone and that he now considers it to be much younger, perhaps Pliocene.

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Notes on Thecal Variation in *Monograptus*

By O. M. B. Bulman

Abstract

Thecal modifications in certain Monograptids are discussed on a basis of restorations which distinguish the theca from the remainder of the "thecal segment" of Törnquist. There seems little support in those bi-form Monograptids examined for the view that the less modified thecae reflect an incomplete development, and in general the new thecal types appear to represent transformations which commonly originate proximally or at least are more highly developed proximally. A possible analogy between this colonial development and metamerism is suggested.

Introduction

IT has long been recognized (e.g. Elles, 1922) that in the graptolites new features may first be seen in the proximal portion of the rhabdosome and particularly is this exemplified in the thecal variation of the Monograptids. Although well-substantiated lineages are rare, this basic assumption of the introduction and spread of new thecal types appears to possess adequate stratigraphical support of a general kind. *Monograptus* first appears in the *M. vesiculosus* zone (*M. atavus* and *M. rheidolensis* [= *acinaces*] zones of Jones, 1909) where it is represented by comparatively few species, of exclusively simple thecal type ; these persist into the *M. cyphus* zone, where they are joined by others of simple type and where hooked thecae first make their appearance (*M. revolutus* and *M. difformis*). The modified thecae are limited to the proximal end, and it is not until the overlying zone of *M. fimbriatus* that the first species appear with modified thecae extending throughout the rhabdosome.[1]

Westoll (in Zuckerman, 1950) has recently attempted to explain these bi-form Monograptids in terms of a "potential hypermorph" concept ; that is to say, there is a known tendency for the thecae of a rhabdosome to increase in size distally to a certain limit, and whilst the proximal thecae may be (in a sense) fully-grown, more distal thecae may not develop or may lose the distinctive apertural modifications because they were unable to grow sufficiently large. Professor Westoll would doubtless be the first to admit that his explanation may represent an over-simplification, but the idea seemed to merit further consideration. For the purposes of such study, existing figures are of only limited value, the majority being based on flattened specimens which often convey a misleading idea of thecal form ; and it was therefore necessary to prepare new figures.

[1] It follows that in attempting to establish lineages, similarity in the distal thecae is at least as important as the character of the modified proximal thecae.

Illustrations

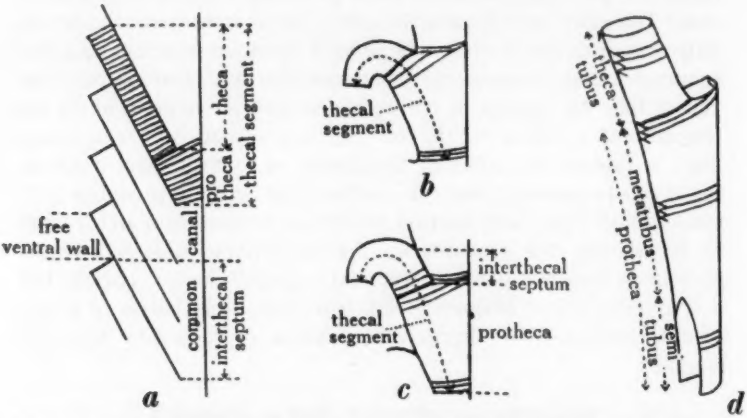
Each key figure (here reproduced × 2) is taken from a typical illustration in the *Monograph of British Graptolites*, enlarged photographically, and bleached after the outline had been traced in indian ink. Individual thecae are restorations (reproduced × 10), in full relief, based on numerous pyritized specimens since limestone material is not available. These may well prove to be inaccurate in some respects, particularly as regards the aperture and possible apertural processes, but they summarize and interpret the most complete information accessible. Where they are known to correspond exactly in position along the rhabdosome to those on the key they are related by a continuous line ; a broken line indicates uncertainty as to their exact position, but it can be assumed that the numbering is accurate to within ± 2. Growth-lines have been inserted not merely to give form and solidity to the thecae, but primarily to indicate successive growth-stages. Sometimes they are partly conjectural, especially as to spacing, but it is surprising how frequently sufficient traces were visible to give a reliable indication of direction (and hence of successive apertural margins).

Relations of adjacent Thecal Segments

The term " thecal segment " was introduced by Tornquist (1899) to designate the theca proper together with its proximal " common canal " portion ; and in the accompanying figures, growth lines are inserted in each instance for one complete thecal segment. Their precise relations at the junctions of thecal segments are not often clear, but th?30 in *M. clingani* (Text-fig. 5) is an accurate drawing of a specimen in which the growth-lines were perfectly displayed ; this agrees with indications given by Münch (1938) and has where necessary been used as a guide to the interpretation of similar thecae.

All the modifications here considered involve some degree of isolation of the apertural region, and this introduces a difficulty in the measurement of thecal overlap, which only readily applies to adnate thecae. Thecal overlap (Text-fig. 1*a*) is the ratio of interthecal septum to total thecal length and is dependent upon thecal length and inclination. The free portion of an isolate theca, however, is equivalent to the distal part of an adnate theca and should be included in the estimate of total thecal length though it does not overlap : with the development of isolation in thecae, it becomes possible to have fully individualized thecae with no thecal overlap at all. Apart from the difficulty of obtaining an accurate measure of the length of a hooked or lobate theca, the conception of thecal overlap ceases to apply ; but at the same time, some means is required of expressing the difference between the two conditions shown in Text-fig. 1*b* and *c*.

Münch (1938) considered the thecal segment to be composed of three parts for which he proposed the names semitubus, metatubus, and thecatubus (Text-fig. 1*d*). The relations of the interthecal septum are still somewhat doubtful: that is to say, it is uncertain whether the interthecal septum is the dorsal wall of the preceding theca (as implied



TEXT-FIG. 1.—Diagrams illustrating the thecal structure of Monograptids.

(*a*) Thecal segment shaded with approximate growth-lines showing protheca and theca in the simple condition of adnate thecae; and the measurement of thecal overlap.

(*b*) Thecal segment of a hooked theca (limits of protheca indicated by growth lines) with no interthecal septum and a prothecal ratio of 100 per cent.

(*c*) Similar thecal segment with short interthecal septum and prothecal ratio of about 70 per cent.

(*d*) Thecal segment with short adnate theca, showing relation of protheca to semitubus and metatubus of Münch (after Münch, 1938).

by Münch), or whether it is the ventral wall of the succeeding theca, in which case distinction between the semitubus and metatubus disappears. Moreover, the metatubus can only be present where the thecal overlap is less than one-half. Recognition of the semi- and metatubus seems therefore undesirable though some name for the proximal portion of the thecal segment is certainly needed, and for this the term *protheca* is proposed. The protheca corresponds approximately at least with the stolotheca of the Dendroidea, and in the accompanying figures the boundary between the theca and the protheca is indicated by a slightly thickened line.

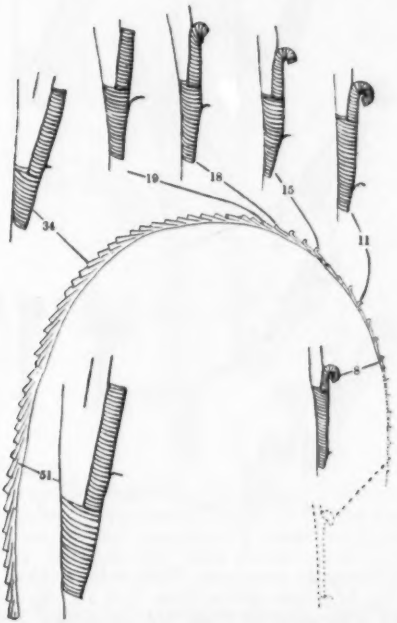
For isolate thecae which still possess a short interthecal septum, what is here termed the *prothecal ratio* may be useful to express the relation of protheca to protheca plus interthecal septum (Text-fig. 1*c*)

which affords a measure of the isolation. With a progressive loss of the hooked portion of the theca (as for example in *M. argenteus*) the prothecal ratio approaches and eventually becomes identical with the complement of thecal overlap.

Descriptive Section

a. M. revolutus—M. argenteus series (Text-figs. 2, 3)

The proximal end is extremely slender, especially in *M. revolutus*, and specimens are rarely found complete ; but the general characters

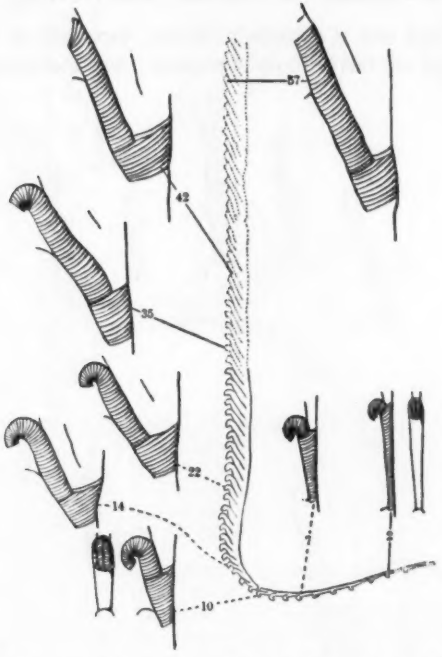


Text-fig. 2.—*Monograptus revolutus* Kurck. *Mon. Brit. Grapt.*, pl. xxxviii, fig. 1*d* (GSM., Pg 1015) ; *M. cyphus* zone, Pont Erwyd. Growth lines largely conjectural.

of the proximal and distal portions are comparable in the two species. Distal thecae have a higher inclination (25° as compared with 15°) and slightly greater overlap in *argenteus* than in *revolutus*, but in both are straight slender tubes of comparable proportions. If *argenteus* is a descendant of *revolutus*, change is not confined to the proximal end, but the amount and quality of change in the distal thecae is only slight. These distal thecae are very similar to those of *M. cyphus*, and *revolutus* could be derived from *cyphus* by a modification of the proximal thecae.

Proximally, the new thecal type introduced is a simple hook, and the thecae remain essentially cylindrical tubes of almost uniform diameter (cf. the triangulate types).

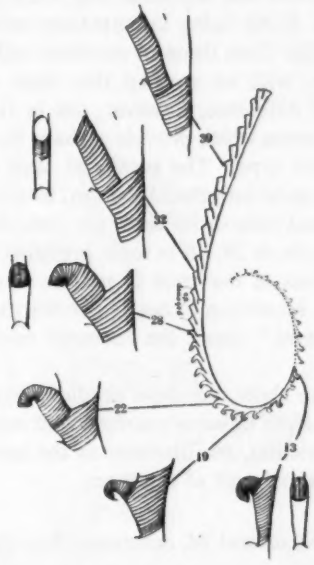
No specimens of *revolutus* were available showing the earliest thecae in relief, but in th 8 the prothecal ratio is about 80 per cent ; to judge from published figures, it is practically 100 per cent in the first two or



TEXT-FIG. 3.—*Monograptus argenteus* (Nicholson). *Mon. Brit. Grapt.*, pl. xxxviii, fig. 5*d* (Birmingham Univ. 713) and fig. 5*b* (SM., A 20940) reversed ; enlargements from SM. A 20940, 20942, and others ; *M. argenteus* zone, Skelgill. Growth-lines partly conjectural.

three thecae, and the hooked portion is so minute as to be almost rudimentary. The hook extends to about 20 thecae and the early ones are more strongly hooked than the later, but the final change from hooked to straight around th 20 is abrupt (compare th 18 and th 19 in Text-fig. 2). There remains a slight " looseness " about the apertural region of the first straight thecae, as though the apertures were virtually detached, but they show no change in direction of growth The prothecal ratio steadily decreases to about 55 per cent in th 18 and in th 19 the overlap is approximately one-half, increasing to nearly two-thirds distally.

The characters in *argenteus* are exactly comparable, but the hooked thecae extend further along the rhabdosome to about th 40 and there is a more abrupt widening of the rhabdosome due to an increase in thecal inclination in the region of th 10–16. There is a slight constriction or narrowing of the thecal tube towards the aperture in the early hooks ; and loss of the hooked character is far more gradual here, so



TEXT-FIG. 4.—*Monograptus difformis* Törnquist. *Mon. Brit. Grapt.*, pl. xxxviii, fig. 4*a* (Birmingham Univ.), *M. cyphus* zone, Dobb's Linn. Growth-lines largely conjectural ; apertural margins of th 29–31 are slightly damaged, but these thecae appear to be straight.

that it is difficult to say just where it entirely disappears. The same " looseness " of the apertural region is noticeable in the earliest straight thecae, and similar decrease occurs in the prothecal ratio from over 90 per cent in th 2, through 40 per cent around th 22, to little more than 20 per cent in th 42, from whence it can be expressed as a three-quarter overlap. The steady decrease in prothecal ratio, and later steady increase in thecal ratio indicates a considerable growth in size of the theca relative to the protheca.

It might appear that these changes could readily be interpreted as being due to a gradual loss of the hooked portion of the thecae distally through incomplete development. However, if the distinction drawn in the preceding section between protheca and theca has a true significance, and the thecal element so defined is comparable throughout,

then the distal thecae cannot be regarded as incompletely developed proximal thecae where the prothecal ratio is 100 per cent and the entire theca is involved in the hook.

(*b*) *Monograptus difformis* (Text-fig. 4)

M. difformis is a somewhat rare species which has hitherto been placed between *revolutus* and *argenteus* (e.g. Elles, 1922), the extent of the hook (to about th 30) being intermediate between those species. The distal thecae differ from those of *revolutus* and *argenteus* in being shorter and stouter, with an overlap that does not greatly exceed one-half; the chief difference, however, lies in the character of the modified proximal thecae which provide perhaps the earliest manifestation of the triangular type. The prothecal ratio is 100 per cent to about th 20, where a short interthecal septum abruptly makes its appearance and the prothecal ratio drops to 75 per cent, decreasing gradually to about 60 per cent in th 28. It is most probable that in this species as in *revolutus* the loss of the hook is sudden. In th 32 the overlap is just over one-half, increasing to nearly two-thirds at th 39, and there is a distinct "looseness" about the apertural regions of the earliest straight thecae.

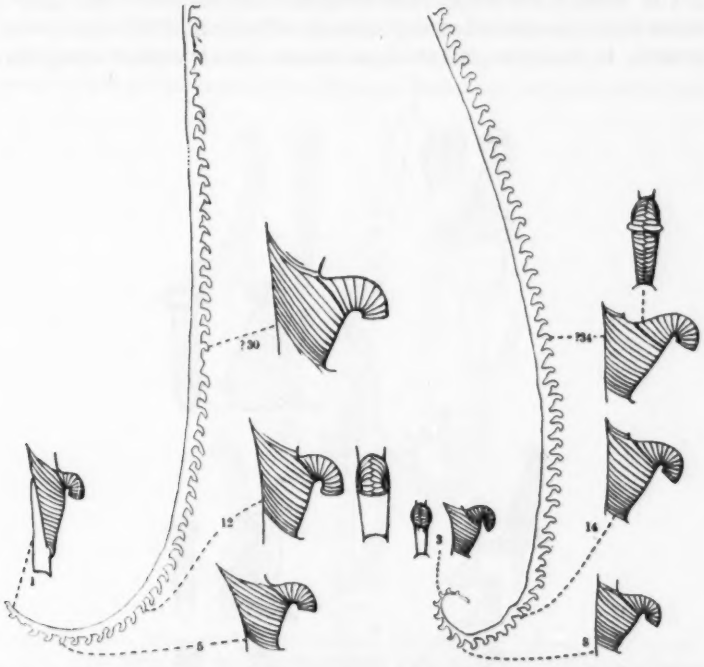
The hooked thecae show the usual gradual reduction in extent of the hook, but differ from those of *revolutus* and *argenteus* in a noticeable apertural constriction, the diameter at the aperture being barely half that of the proximal part of the theca.

(*c*) *M. clingani* and *M. communis* (Text-figs. 5, 6)

Both these species seem to represent early stages in the triangulate type of Monograptid [1] which quickly becomes established as the characteristic element of the *M. gregarius* zone; a prothecal ratio of 100 per cent persists to the distal extremity and the thecae change very little in form throughout the rhabdosome. The triangular character is not so pronounced in *clingani* by reason of the smaller size of the theca (as compared with the protheca) and the relatively larger and less constricted hook: in *clingani* the whole theca is involved in the hook, whereas in *communis* the distal thecae show a considerable isolate portion which terminates in a hook. *M. communis* is therefore not likely to be ancestral to *clingani* though it makes its appearance in an earlier zone; and the absence of interthecal septa makes *clingani* an improbable link with the *priodon* series, whose connection with *argenteus* therefore remains uncertain.

[1] A group recognized in the key classification adopted for the *Monograph of British Graptolites*, but not referred to by Elles (1922) in her discussion of thecal evolution.

Both show a very slight indication of a feature rather characteristic of the truly triangulate thecae, namely, a transverse broadening of the aperture, which in extreme cases (such as *M. decipiens*) becomes



TEXT-FIG. 5.—*Monograptus clingani* (Carruthers). *Mon. Brit. Grapt.*, pl. xlvi, fig. 11*d*; enlargements from SM. A 21267 (*M. convolutus* zone, Abergwesyn), and SM. 23463–4 (Spengill, Sedbergh). Growth-lines exact for th? 30.

TEXT-FIG. 6.—*Monograptus communis* (Lapworth). *Mon. Brit. Grapt.*, pl. xlix, fig. 1*b*; enlargements from SM. A 21489 (Skelgill) and SM. 23465–6 (Rheidol Gorge, Pont Erwyd).

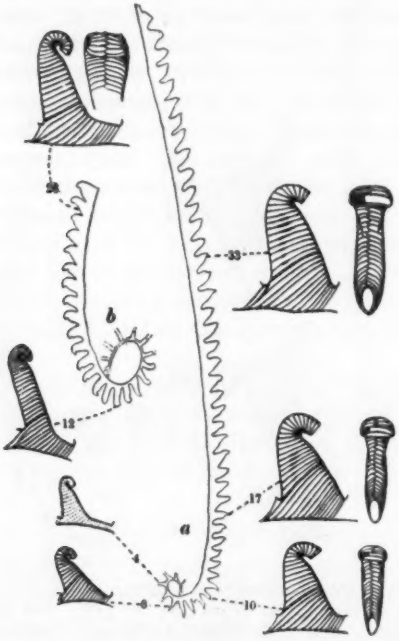
a mere transverse slit. At the inner side of the hook, the thecal wall is flattened so that the cross-section of each thecal segment changes from almost circular through more or less triangular to transversely oval, and there is some indication of lateral lappets to the apertural margin.

(*d*) *M. fimbriatus—M. triangulatus* series (Text-figs. 7, 8)

M. fimbriatus is a highly-developed representative of the triangular type though it occurs early, at the base of the *M. gregarius* zone (*M. fimbriatus* sub-zone). It could possibly be related to the contemporary *communis*, but shows even in the distal thecae a far greater elongation

(isolation) and a relatively smaller hook. There is no interthecal septum (the prothecal ratio is 100 per cent throughout the rhabdosome) and the thecae are entirely triangular or isolate.

The series : *fimbriatus—raitzhainiensis—triangulatus*—var. *major* : seems firmly established stratigraphically (Challinor, 1945) and is well-graded. In *fimbriatus*, the protheca remains almost entirely triangular,

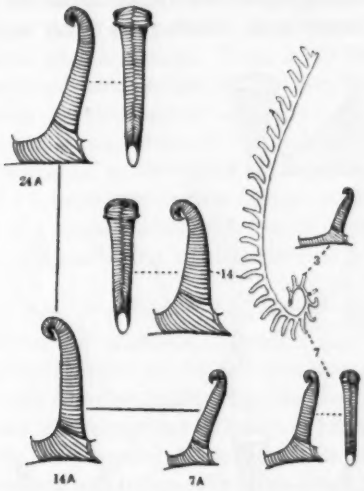


TEXT-FIG. 7*a*.—*Monograptus fimbriatus* (Nicholson). *Mon. Brit. Grapt.*, pl. xlviii, fig. 4*c* ; enlargements from SM. A 23468 (near var. *similis*), Rheidol Gorge, Pont Erwyd, and SM. A 21461, Skelgill.
7*b*. *Monograptus raitzhainiensis* (Eisel). *Mon. Brit. Grapt.*, pl. xlviii, fig. 3*a* ; enlargements from SM. 23469, Mealy Gill, Coniston.

with a highly-inclined ventral wall, and the theca is isolate, flattened in the plane of the rhabdosome proximally, and flattened transversely in the hooked termination, the thecal aperture being almost slit-like. Proximally, the thecae are generally similar in var. *similis* though apparently less transversely-flattened in the hook ; but in *fimbriatus s. str.*, the proximal thecae tend to be more widely-spaced, separated by a short cylindrical prothecal section which expands abruptly into the base of each theca.

In *raitzhainiensis*, the proximal thecae are isolate and tubular,

nearly four times as long as wide, with a small constricted apertural hook. Even distal thecae are typically well-spaced, the initial part of each protheca being tubular and expanding abruptly into the thecal base ; the thecae are semi-tubular, transversely compressed in the region of the hook which, though small, is more completely developed than in *fimbriatus*. It will be remarked that distal thecae of *raitzhainiensis* are as isolate as proximal thecae of *fimbriatus* (more so than those



TEXT-FIG. 8.—*Monograptus triangulatus* (Harkness). *Mon. Brit. Grapt.*, pl. xlvii, fig. 4*a* ; enlargements from SM. 23470 Rheidol Gorge, Pont Erwyd.

Enlargements with the suffix A are *M. triangulatus* var. *maior* Elles & Wood, SM. 23471–2, Pont Erwyd ; growth-lines exact.

of var. *similis*), and the proximal thecae are more *Rastrites*-like than any of the proximal thecae of *fimbriatus*.

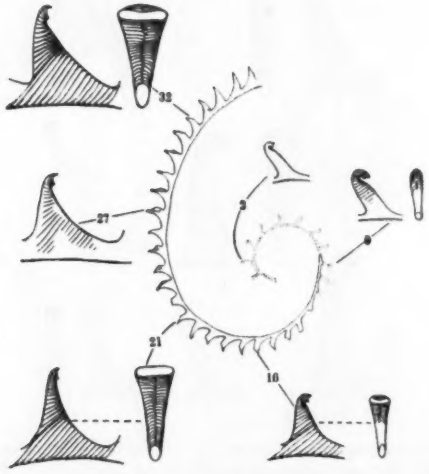
In *triangulatus* these tendencies are still more fully developed, reaching their maximum in var. *major*, where all the thecae are slender cylindrical tubes rising abruptly from a " common canal " of about the same diameter, and terminating in a compact, transversely-compressed hook. The relation of length to diameter for all the thecae is about six to one, and proximal thecae differ from distal ones mainly in size and in being relatively more widely spaced ; the rhabdosome is essentially a robust *Rastrites*.

At no stage in the series can it be said that the distal thecae resemble early stages in the development of proximal thecae, and the change is rather different in character from that of the *revolutus–argenteus* series. The *fimbriatus* series exhibits not so much the spreading of a new

thecal type along the rhabdosome as a progressive isolation which, though it affects all thecae of the rhabdosome, is always more advanced proximally than distally.

(*e*) *Monograptus decipiens* (Text-fig. 9)

M. decipiens is a typical example of bi-form Monograptid with essentially triangular thecae. So far as can be determined, the distal thecae have an exaggerated transverse flattening of the aperture, terminating in a small hook, which gives rather variable appearances



TEXT-FIG. 9.—*Monograptus decipiens* Törnquist. *Mon. Brit. Grapt.*, pl. xlvii, fig. 3*b* (GSM. 26315), *M. convolutus* zone, Pont Erwyd ; enlargements from the same specimen and from GSM. 26316 (*Mon. Brit. Grapt.*, text-fig. 325*a*), Pont Erwyd.

on compression. In true profile, the thecae are acutely triangular, but the transverse apertures are readily displaced ; if partly concealed by a film of matrix, the effect is that of true profile, but fully exposed they may then appear as stoutly isolate thecae, obliquely truncated at the aperture (Text-fig. 9).

The transverse flattening of the aperture is more marked distally than in the middle of the rhabdosome where the thecae are otherwise similar, which suggests that the distal thecae are undergoing change independent of the proximal thecae. Proximally, the thecae are isolate and widely-spaced, with tubular prothecae expanding abruptly into the thecal bases. It has never, I think, been suggested that *decipiens* is a stage leading to any Rastrite species, and this species (with others of comparable horizon) seems to represent a relatively stable condition

of half-developed *Rastrites* (like the relation of Sub-Holostei to Holostei among fishes). Eisel's term *Demirastrites* would perhaps have been appropriate for such forms, but unfortunately the genolectotype of that genus is *M. triangulatus*.

Conclusions

Graptolites are colonial organisms, and the rhabdosome of *Monograptus* consists of a succession of individuals developed in a single series, not separated from one another by a sexual generation but subject to a common genetic control. There is, so far as I am aware, no work on the genetics of colonial animals and very little on the general principles of colonial development or astogeny ; concepts borrowed from simple ontogenies may become misleading when applied to astogeny. Each individual in the rhabdosome has an ontogeny complete in itself, and it is important to keep distinct the ideas of change in successive thecae of a single rhabdosome (which constitutes astogeny) and the relation of a succession of rhabdosomes (which constitutes phylogeny).

In coining the term " bi-form " for certain Monograptids, the authors of the *Monograph of British Graptolites* (and later Miss Elles, 1922) were directing attention to the fact that new thecal types may develop in a part only (the proximal part) of the rhabdosome. A somewhat similar feature was recognized by Smith & Lang (1930) under the term " genomorph " as applied to compound corals : in fact, the bi-form Monograptids are comparable with the genomorphic coral " genera ", though far more regular. In this connection, it may be suggested that budding from a stolon is likely to produce greater regularity than can occur among those organisms where each zooid, as soon as it is established, can itself give rise to others by individual budding.

It would seem *a priori* that changes of phylogenetic significance could affect all individuals of a colony equally or could be limited to proximal or distal regions, ending (or beginning) either abruptly or gradually. There is a suggestion (in the character of the distal thecae of *M. decipiens* and *M. communis*) that new features may originate or be dominantly expressed distally, but an appearance limited to the proximal end is far more common. Limitation to one or other end of the rhabdosome could be due, among other causes, to incomplete development of the less-modified thecae ; but when the true theca is distinguished from the protheca (= stolothecal equivalent), there is little ground for attributing the observed changes to such a cause even in the *argenteus* series. There is more justification (in most of the instances described above) for the orthodox view that the new types are transformations of thecal form introduced proximally into the

rhabdosome ; with the corollary that the factor concerned loses its potency as the colony ages. Hypermorphosis or perhaps more strictly Retardation (de Beer, 1940) remains, however, a possible interpretation of the retrogressive hook series (not here investigated).

If any comparison with simple ontogeny is of value, perhaps the most satisfactory analogy lies in the development of metamerically-segmented animals such as the Arthropods ; and though the soft parts of the graptolite are of course unknown, there may well have been something corresponding to the Pterobranch terminal bud or " blastozoid inachevé " to represent the Arthropod telson. It is a very general rule (e.g., Calman, 1926) among Arthropods that specialization begins anteriorly (i.e., the first-formed segments) and works backwards. Successive moults define successive growth-stages in arthropod limbs, and the anterior limbs have of course a longer developmental history than posterior ones. Sometimes the changes they exhibit are in proportion only (i.e., are simple growth-changes related on a growth-gradient to absolute size and length of development) ; but in other instances (as with the replacement of biramous by phyllopodous limbs in *Lepidocaris*) the change is more in the nature of substitution.

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The London Clay of Coastal Suffolk and Essex

By A. G. Davis and G. F. Elliott

Abstract

The London Clay exposures on the coasts of Essex and Suffolk are described and their fossils listed. Correlation is made with similar strata in Germany and Denmark, and the significance of all these beds in relation to the Lower Eocene palaeogeography of North-Western Europe is indicated.

In view of the forthcoming publication by the British Museum of a further volume on British Tertiary plants it is desirable to place on record the results of a search for plant remains undertaken by the authors in 1937–8 in the London Clay exposed along the coasts of Suffolk and Essex between Bawdsey and Shoeburyness.

Samuel Dale (1659–1739), physician and apothecary, friend and executor to John Ray, was the first to describe the London Clay of this region, in the vicinity of Harwich (1704 and 1732). During the nineteenth century local references were made by Mitchell (1837) Clarke (1840), Whitaker (1877, 1906, and 1918), and Dalton (1880). Since 1900 work has been carried out by Johnson (1901), Thompson (1911), and Boswell (1916 and 1928). The present account deals with information which is new or only briefly mentioned in the references just cited.

Suffolk

Part of the London Clay occurs in the east and south-east of the county. Transgressive overlap of the Pliocene Waltonian has removed the older formation entirely or reduced its thickness to about 10 feet over all but a coastal strip some 10 to 12 miles in width, within which the London Clay thickens rapidly, being 83 feet at Felixstowe and 160 feet at Lowestoft. The strike is north and south over East Suffolk, with an eastward dip of 1 in 420 feet at Saxmundham (Strahan, 1916, p. 56), and 1 in 135 feet near the coast ; to the south the strike swings round to E.N.E.–W.S.W.

Stratigraphy and Palaeontology

(1) *Bawdsey Cliff.*—In the cliffs one mile north-east of Bawdsey Ferry northwards to the first Martello Tower, between 11 and 20 feet of blue London Clay are seen, without concretions and overlain by Red Crag. Only pyritized wood, unattacked by borers, was noticed in the clay. Washed samples taken from an excavation at H.W.M. for Air Ministry Works yielded an abundance of pyritized diatoms and radiolaria. Much pyritized debris and drift wood is cast up on the beach and at the present time pyritic patches are being formed by tidal action between the Air Ministry Works and the Martello Tower.

An examination of the debris yielded *Odontaspis macrota* (Ag.), *O. sp.*, *Otodus obliquus* (Ag.), and a few fruits to be described in the forthcoming B.M. monograph. Septarian concretions occur loose on the beach and may be derived from beds below tide marks. The thickness of the London Clay at this spot as shown by well records is 87 feet (Whitaker, 1906, p. 22). The diatom-bearing clay is also in the lower 100 feet of the London Clay at Prittlewell and Sheerness (Shrubsole, 1881, p. 383), and at Wimbledon (Davis, 1928, p. 344).

(2) *Felixstowe.*—Along the foreshore northward towards Bawdsey, locally known as " The Rocks " (Lingwood, p. 145), the characteristic cementstone of Harwich forms an alga-clad reef. The accumulation of sand and shingle over the clay prevented a search for fossils. Mitchell (1837, p. 259) collected fossils here and only the following can be recognized : *Cyprina* sp. small, *Modiolus* sp., and *Nautilus* sp. The London Clay is not more than 60 feet thick at the Felix Hotel (Bosweli, 1928, p. 68).

(3) *Landguard.*—The foreshore on the south of Felixstowe and towards Landguard is similar to the above and in a similar condition. Mr. J. S. Davis in 1918 found teeth of *Odontaspis macrota* and lignitic wood cast up from beds exposed below tide marks.

(4) *Shotley Cliff.*—The cementstone of Harwich outcrops on the foreshore of the cliffs opposite Harwich railway station. Odontaspids and drift wood were the only fossil remains noticed. Inland there were formerly brickyards ; Walcott (1860), recorded *Nautilus* sp., *Modiolus* sp., *Cyprina* sp., *Protocardium* sp., and drift wood.

Essex

The London Clay, except for the passage beds at the top, consists almost entirely of soft brown or blue-grey clay with occasional layers of septaria or concretions. Its thickness has been proved by well borings at Ingatestone (530 feet maximum) and at Great Warley (493 feet where it is overlaid by Bagshot Beds). Although attaining its full development under outliers of Bagshot Beds, it has elsewhere suffered thinning by denudation prior to the deposition of the Crag beds, but there may be upwards of 300 feet (Strahan, 1916, pp. 55–6).

Stratigraphy and Palaeontology

(1) *Harwich.*—The cliff and foreshore, commencing at the lighthouse to the breakwater at Blackmans Head, is the classic section of Samuel Dale. The London Clay is still to be seen and it may be observed that the original chronicler was a most faithful one for his description is not altered by later investigation. Since Dale's time coast erosion has cut back the cliff at the point where he figured it (pl. VIII, 1732), and at

the present time the beds seen by him are displayed on a gently shelving foreshore. The capping of Crag (Waltonian) has entirely disappeared and a sea wall with fortifications mantles part of the London Clay.

Sequence at Harwich

(*a*) Basal pebble bed (Thompson, 1911, and Boswell, 1916, pp. 564–8). Dredged in the harbour and proved in local borings.

(*b*) Blue Clay, proved by borings 23 feet (Whitaker, 1918, p. 184). The surface of this bed forms the foreshore between tide marks and is the " Platimore " of authors, a name still in use by inhabitants of the district. The terms " platamore " and " platiment " are also used.

(*c*) Resting upon the platimore is a cement stone one foot thick forming a continuous platform well exposed at low water. It is divided into rounded tabular blocks, one of the largest seen measuring 30 feet in length. The stone is extremely tough and resistant to the weather. Dale records that in his time the streets of Harwich were cobbled with dressed cement stone taken from this bed.

Many of the blocks show shrinkage cracks which are not infilled with a subsequent deposit ; in addition there are large diagonal partings up to 4 inches wide filled with calcite which resists weathering. It is a lithic type quite unfamiliar to observers of the more southern facies. Near Croydon, Surrey, Davis and Wrigley (1926, p. 434) noted three continuous layers of tabular stone 3 inches thick separated by 5-foot intervals, at a level between 25 and 50 feet above the base of the London Clay.

The Harwich cement stone is covered with a dense growth of living algae preventing an adequate search for fossils. Among those figured by Dale only *Cyprina* sp. (? small form of *C. planata* J. de C. Sby.), and an indeterminable fusoid gasteropod can be recognized now. Prestwich obtained *Pitaria* sp., *Cyprina* sp., and *Modiola depressa* (Prestwich Collection, British Museum, Nat. Hist.). The type of *Modiola undulata* S. Wood (Geological Survey Museum) is probably from this rock.

(*d*) The beds above the cement stone are obscured by the sea wall and redoubt. In April of 1938 excavation for a new road from the Lighthouse, parallel with the shore and towards Tower Hill exposed the beds above the cement stone and showed a layer of true septaria (*ludus helmonti* of Dale) at the level of the top of the sea wall. Some 40 or more feet of London Clay above the septarian layer forms Tower Hill. No fossils were observed. The absence of selenite may indicate an originally barren deposit.

Owing to the protective works on the shore, erosion has ceased and pyritic debris, formerly collected for copperas, is not now so plentiful. A few patches occur near the Breakwater and in these were found *Odontaspis macrota* and *O. hopei* (quite common) and more rarely *Otodus obliquus* and remains of a bony fish. These are derived from bed (*b*). Relics of the Waltonian Crag are to be found in the beach material in the form of pebbles of comminuted shell rock and red tabular pieces of cement stone with *Pholas* borings which are a feature of the base of the Crag at Walton-on-Naze.

(2) *Lower Dovercourt.*—Odontaspid teeth and drift wood occur along the foreshore in the pyritic patches and are derived from the platimore.

(3) *Walton-on-Naze.*—Blue tenacious clay is seen for 10–20 feet underlying the Waltonian Red Crag and outcropping on the foreshore southward of the Watch Tower. Septaria are present just above H.W.M. but not common, and much drift wood in the form of lignite. Fish remains have been recorded by Davis (1937, p. 79), and a

pyritic cast of *Cyprina* sp. (? small form of *Cyprina planata*) has been found. A sample of clay taken near the line of septaria has yielded a residue of diatoms and radiolaria. The Waterworks Well (Whitaker, 1918, p. 294) provides evidence that the site from which the diatom sample was taken is only 67 feet above the Pebble Bed. The cement-stone of Harwich was encountered about 25 feet above the Pebble Bed.

(4) *Walton Cliffs.*—One mile south-west of Walton pier and two miles north-west of Frinton. From 50 to 60 feet of blue clays are exposed in cliff with three major layers of septaria situated at roughly even intervals, and the foreshore is composed of stiff blue clay; erosion produces a strand of pyritic and septarian debris between tide marks. Johnson (1901, p. 287) gave a list of fossils found by him and the British Museum (Nat. Hist.) has received from Mr. S. Hazzledine Warren a further collection containing a rare *Vulsella*. Many of these records have been confirmed and the following are additions: *Nautilus regalis*, *Tibia lucida* (J. Sby.), and "*Granularia* sp.". Fucoidal-like markings, tubes, and worm-like burrows and markings abound on septarian surfaces. Johnson first produced evidence of a flora; the best site for collecting was found near the end of the sea wall from Walton, and among the fruits obtained was *Jenkinsella apocynoides* (Reid and Chandler) one of the most characteristic plants of the Herne Bay–Swalecliff flora of Kent. The fauna and flora is very similar to and may be correlated with the *Balanocrinus* horizon of Herne Bay. A sample of clay from the best fruit site was taken about four feet above H.W.M. and yielded diatoms.

(5) *Frinton Cliffs.*—Cliff sections exposing London Clay continue southward but are considerably obscured by protective walls and planted shrubberies. *Balanocrinus* has not been found and particulars of local wells suggest that this horizon has been lost by denudation.

(6) *Holland-on-Sea.*—In the cliffs and foreshore on either side of path descending to beach at Fiddle Dock 10–15 feet of stiff blue tenacious clay are exposed beneath thicker Glacial deposits. After a scour of the sands good foreshore exposures are available as far as Clacton Pier. Septarian concretions with their surfaces encrusted and bristling with fucoid, vermiform, and other problematic bodies occur in two layers situated above and below H.W.M. The presence of plant remains suggests that further collecting is desirable. Lignite in the form of small pieces or large logs is common and is rarely found attacked by the *Teredo*. A fine example of *Petrophiloides richardsoni*, a characteristic plant of Herne Bay and Swalecliff was found *in situ* on the foreshore at Fiddle Dock. *Nipa* sp. also occurs but *Cerithiella charlesworthi* (Prestwich) was the only mollusc found in an exposure

of very considerable extent. *Terebratulina wardenensis* Elliott was found to the south of Fiddle Dock. *Balanocrinus subbasaltiformis* (Miller) was prolific in the form of loose pyritic replacements and formed a considerable part of the pyritic debris which collects at the foot of the shingle. More rarely this fossil may be seen in the septaria, usually preserved in calcite. Examples in every stage of abrasion may be picked up all the way to Clacton. *Odontaspis macrota* and *O. hopei* are frequent but small. "*Granularia*" occurs on the surfaces of septaria together with remarkable spiral worm tubes, an account of which is being prepared by Mr. A. G. Wrigley. They are quite plentiful and appear to be distinct from the larger spirals found at a similar horizon in the London area, i.e. Beddington Lane, near Croydon, and the South London tube railway tunnels—Kennington to Clapham. These remarkable objects, which are so abundant on the septarian surfaces, are at present unnamed. *Graphularia wetherelli* (M. Edwards & Haime) occurs in the clay and in small nodules in which the pen forms the nucleus.

(7) *Clacton.*—A foreshore of London Clay is visible between Holland and Clacton Pier after the sand is scoured and there is considerable septarian matter lying about. Local wells show that 100 feet and more are present below L.W.M.

(8) *Jaywick Sands.*—Sea walls obscure the low cliff sections, but there is an interesting foreshore between Martello Tower [1] and north of Pleistocene Channel at Lion Point, showing a London Clay surface with Pleistocene erosion and channelling (Warren, 1933, pp. 15–19, and Oakley & Leakey, 1937). Near the Martello Tower and Battery and between tide marks there is buttery black marsh clay with *Scrobicularia* (Bed T.S. of Warren, 1933, p. 17). Many small black pebbles and pyritic matter with *Balanocrinus* are washed out of this deposit. Further westward the marine Pleistocene with *Ostrea* (M1 of Warren, 1933, p. 19) contains many decayed pieces of London Clay septaria and rare *Balanocrinus* stems.[2]

(9) *Lion Point, Jaywick Sands.*—Foreshore from Lion Point towards St. Osyth. On the eastern bank of the Pleistocene Channel, *Elephas antiquus* Bed (Warren, 1933, and Oakley & Leakey, 1937), a septarian nodule *in situ* yielded *Balanocrinus* and *Graphularia wetherelli.* The London Clay foreshore also yielded *Balanocrinus* and Odontaspid teeth. The septaria bear fucoidal markings and yield, rarely, *Nautilus*

[1] Marked Battery on Ordnance Maps of 1912 and situated well inland. The masonry and armament of the Napoleonic Wars are now (15.6.38) lying at low water.

[2] In this bed was found a fragmentary molar of a Pleistocene *Rhinoceros* which has been deposited in the Museum of the Royal College of Surgeons, Lincolns Inn.

imperialis. Lying loose upon the Freshwater Channel deposits were found further *Balanocrinus* and an eroded example of *Nautilus regalis*, no doubt derivatives washed out of these beds. A sample of London Clay taken at Lion Point, associated with *Balanocrinus* yielded diatoms.

(10) *St. Osyth.*—Indifferently exposed clay with many septaria occurs in the low cliffs and foreshore from Lion Point to St. Osyth. Only *Balanocrinus* and *Nautilus imperialis* have been found.

A boring at Clear Bay showed :—

Drift . .	.	16 feet
London Clay.	.	100 feet
Reading Beds	.	54 feet
		to Chalk

(11) *Shoeburyness.*—(From information received from Mr. A. G. Wrigley.) The foreshore is exposed at favourable tides showing well developed septarian layers and clay with *Nipa* and large Odontaspid teeth. The London Clay, according to well borings, attains a thickness from 380 to 400 feet and the *Nipa*-bearing horizon can be correlated with the higher beds of Brentwood, Essex, and Sheppey, Kent.

General Remarks

The stratigraphical position of *Balanocrinus* and its associated flora in Suffolk and Essex confirms previous knowledge of these beds in the London Clay of the London and Kent areas (Division 2 of Wrigley, 1924).

Diatoms were known to occur in the relatively barren Division 1. Shrubsole (1881) found a diatom flora in the lowest 43 feet of the London Clay at the Prittlewell Well, near Southend, Essex. This fact was used by him as a control for establishing the vertical distribution of diatoms in the London Clay. The finding of a flora at Bawdsey was fully expected. The forms found in the new localities are rich in *Coscinodiscus* spp. and *Trinacria* spp., but no attempt has been made to arrive at determinations. Abundant at low levels, they become increasingly rare as the 100-ft. level is approached and no trace of them is found higher. Examination of samples west of the London area has so far not produced diatoms.[1]

Consideration of this lowest clay, diatomaceous but almost barren of macrofossils, leads naturally to comparison with similar strata elsewhere. In North-West Germany and Denmark the solid geology is largely covered by glacial and post-glacial accumulations, but there is a considerable literature on the numerous borings as well as surface

[1] Radiolaria frequently occur in the Suffolk and Essex diatomaceous samples ; usually they are reduced to mere fragments of meshwork but one large form *Spongodiscus* is very robust and plentiful. It ranges well up into the 200-ft. level and has quite recently been noticed at Whitton and Staines, Middlesex, and at London localities.

exposures of the area, largely summarized for the older Tertiary in Müller (1937), Staesche (1938), Wirtz (1939), and Bettenstaedt (1949). The best-known deposit, well-exposed at the surface, is the Danish Möler, a clay with numerous tuff bands or layers of volcanic ash, which yields a rich diatom flora as well as fish remains and other macrofossils, and is referred by Madsen (1928, pp. 70–1) to the Lower Eocene. Similar beds are met with in borings in the North-West German area : Müller refers these to the Palaeocene, but Wirtz and Staesche agree in placing them at the base of the Lower Eocene. Wirtz (1939, text-fig. 4) shows the area of volcanic ash deposits in the Lower Eocene Sea over what is now Germany and Denmark, a feature possibly due to volcanic action in Scania and unknown in the English London Clay.

Staesche (1938, p. 734), who discusses the micropalaeontological classification of the older Tertiary, begins his Division 1 of the Lower Eocene with the ash-beds and succeeding clays : this basal division, up to 100 m. thick, is stated to be especially characterized by abundant diatoms, though these fossils occur sparingly both below and above, and by microfossils here recognized as pyritic moulds of the radiolarian *Spongodiscus* (ref. footnote, p. 334), described in Germany by Schuh (1930) from an apparently equivalent horizon in a boring in Mecklenburg, and by him considered as possible pyritic moulds of algal cells. Wirtz correlates Staesche's Division 1 with the lowest London Clay. Finally Elliott (1948, p. 72) has drawn attention to the record of *Terebratulina* and *Pentacrinus* in the lower portion of beds referred to the London Clay in the German boring Cuxhaven 10, suggesting that this is probably the *Terebratulina wardenensis–Balanocrinus subbasaltiformis* association described above from the Essex coast.

In England, the differences, lithological and faunal, between the London Clay of the Hampshire and London Basins are well known, even although these basins owe their present form to denudation of an originally continuous deposit. The rich shelly faunas of Highgate in the London area, similar to the Hampshire Basin mollusca, are exceptional and are at the very top of the formation, while to take a recent example, the extensive microfauna of the Lower London Clay at Clarendon in the Hampshire Basin (Elliott, 1945) did not yield diatoms as do the otherwise barren basal clays of Essex and the Continent. The London Clay of the London Basin thickens eastwards ; the German–Danish deposits open westwards. Müller's palaeogeographic maps show the Palaeocene and Lower Eocene seas extending as an eastward gulf across North-West Germany, South Denmark, and the South-West Baltic area, opening westwards to what is now the North Sea area. Text-fig. 14 of Wirtz indicates this west-to-east synclinal axis as persisting from Upper Cretaceous to Oligocene. The major

portion of the London Clay Sea lay across the site of the present-day North Sea, and subsidence permitted the accumulation of several hundreds of feet of fine sediment in this basin, which may have opened to the north between the Thulean and Scandinavian land masses. The Scanian, and possibly Thulean volcanic activity was perhaps another expression of the same earth-movements. The German London Clay may be in part older than the English (cf. Wrigley, 1940), which latter rests like the Dutch and Belgian on transgressive basement-beds. The Hampshire Basin gives evidence of a shallow, warm-water Tethyan connection, the junction with the London Basin area possibly not occurring until some time after deposition had started in the northern basin, but even intra-basinal correlation is not easy in the former (Wrigley, 1949).

The difficulty of correlating the London Clay of England and Belgium with the Paris Basin is obvious with the discovery of English beds of Cuisian age overlying the London Clay (Wrigley & Davis, 1937). The main Lower Eocene basin, however, lay across the area of the present North Sea with Tethyan connection in the south-west only, and shallow-water deposition was at a minimum in the Paris Basin. To this northern basin, now mostly covered by sea and younger rocks, the *Balanocrinus* horizon and the diatomaceous lowest London Clay below bear witness to-day on both sides of the North Sea.

Notes

I. *Rapid Method of detecting Diatoms in London Clay Samples*

First thoroughly dry the sample. Drop a piece not much larger than a cube of sugar into a beaker of water. When the clay has broken down, stir with a camel hair paint brush. Count up to 100 and pour off half the contents of the beaker ; do this three or four times after refilling and reducing the count each time to a final count of 40. By now the solution should be clear and a dark residue of pyritic silt should be visible on the bottom of the beaker. Transfer a sample of the residue with a pipette to a 3 inch by 1 inch glass slip and dry off on a hot plate. It is advisable to prevent loss to add a trace of fixative to the drop on the slip ; ordinary gum or gum tragacanth is effective. As soon as dry, cover with balsam and cover glass in the usual manner. If the residue contains coarse material, remove by using a fine mesh sieve ; the use of sieves in the preparation of diatom samples is otherwise not to be recommended.

II. *The London Clay at Cocks Clark, Purleigh, Essex*

The late Professor J. W. Gregory sent to one of the authors (A. G. D.) in 1929 some fossiliferous septaria from this locality which contained an abundance of arms of the brittlestar *Ophioglypha wetherelli*

Forbes and shells of the Pteropod *Valvatina* sp. Both of these species are common in the higher beds of Tolworth, Surrey, Brentwood and Rayleigh, Essex, and Sheppey, Kent. Borings at Purleigh have proved the London Clay to be between 334 and 390 feet thick (Whitaker, 1918, p. 131).

III. *A Pleistocene Section at North Shoebury*

One of us (A. G. D.) has received from Mr. A. G. Wrigley a small collection of shells obtained in 1914 by the late Major Peile. There seems to be no published account of the occurrence and as the collection is well documented the facts are here recorded. The section was in a brickyard near Kemsley's tomato houses at North Shoebury, Essex, and exposed soil and brickearth 6 feet, gravel 9 feet and below, silty clay with shells.

The following mollusca occurred in this shelly bed :—

Corbicula fluminalis (Müller), very common.
Bithynia tentaculata (Linné), frequent.
Paladihlia radigueli (Bourguignat), very common.
Valvata pisinalis (Müller), four examples.
Pisidium sp. indet., one valve.
Cardium edule (Linné), two small examples.
Mytilus sp., a few fragments.

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Quantitative Measurement of Available Relief and of Depth of Dissection

By G. H. Dury

ABSTRACT

Simple arithmetical techniques are set out whereby planimetric data, of the kind used in constructing area-height diagrams, can be made to yield additional quantitative information useful in description and comparison of relief. The most useful is an expression for *mean available relief*, which takes account of the form as well as of the height of interfluves. It is also shown how the depth of dissection of a datum surface can be mapped and measured.

THE planimetric data used in the construction of area-height diagrams (hypsometric and clinographic curves, and height-frequency histograms) can be made to give a quantitative measurement of available relief.

By *available relief* is meant that part of the landscape which, standing higher than the floors of the main valleys, may be looked on as available for destruction by the agents of erosion working with reference to existing base-levels. It is obvious that as the streams of an area cut down, local base-levels will be progressively lowered : nevertheless the assessment of available relief is of use in the comparison of one landscape with another at any given time.

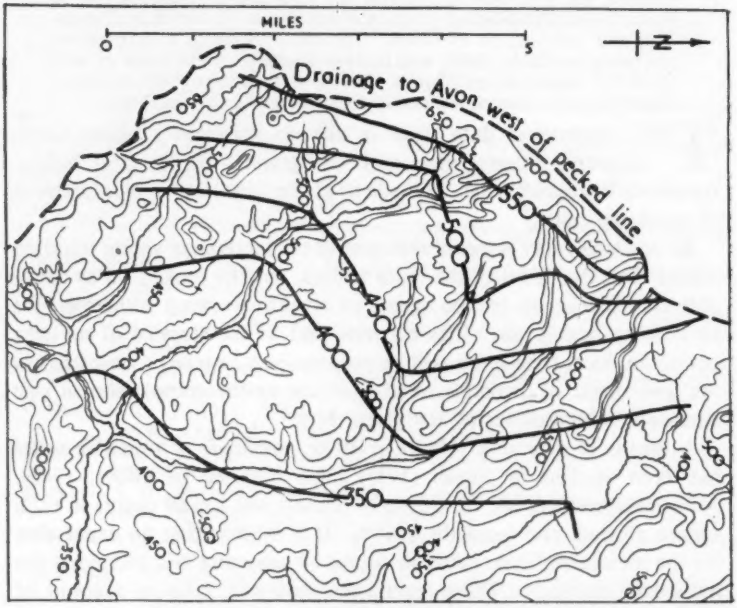
A means of assessing *relative relief* or *amplitude of available relief* has been applied by Smith (1935) (also outlined in Miller, 1948). An area is gridded, the difference of highest and lowest points in each square plotted, and isopleths drawn. It is evident that an expression for the mean amplitude could be found by summing and averaging the individual readings. These techniques, however, take no account of the form of interfluves, the relative height of which is alone measured. Two contrasted landscapes may be imagined, one with narrow deeply-cut valleys and one with wide vales separated by residuals, where the amplitude of available relief measured in this manner is identical.

If the volume of rock contained in interfluves is to be considered, a surface must be defined on which relative relief is zero. Such a surface is the *streamline surface*, which passes through the bottoms of main valleys. It is shown by contours crossing the interfluves to join corresponding intersections of rivers and actual contours (Text-fig. 1).[1]

When the actual surface of a given area is planimetered, the volume of rock between O.D. and the actual surface can be simply calculated. If the streamline surface is also planimetered, and the volume between that surface and O.D. determined, the difference of the two volumes is the total volume of the main interfluves. Divided by the total area, this gives the *mean available relief*.

[1] It is the streamline surface that some early workers on long-profiles mistakenly interpreted as the base-level of a system of graded streams : for a discussion, see Baulig (1925).

The calculations of volume are a matter of simple arithmetic. The planimetric data may be imagined as plotted in a hypsometric curve (Text-fig. 2), which differs from the usual form in that abscissae represent cumulative areas, not percentages of the total. The curve so plotted may be regarded as the end-face of a solid of length one mile,



TEXT-FIG. 1.—Contours of the streamline surface (heavy lines) in the Edge Hill Plateau.

as shown. The area in square miles *abcd* between the contours *a* and *b* is then the same as the value of ab^1. The volume of that part of the solid contained between the contours *a* and *b*, assuming a constant slope between them, is given by

$$V = VI\left(\frac{l_a + l_b}{2}\right)$$

where *VI* is the contour interval and l_a, l_b the total areas enclosed by the respective contours.

For the whole of such a solid, the ordinates of which are $l_0, l_1, l_2 \ldots l_n$, the total volume is given by

$$V = VI\left(\frac{l_o + l_n}{2} + l_1, l_2, + \ldots l_{n-1}\right)$$

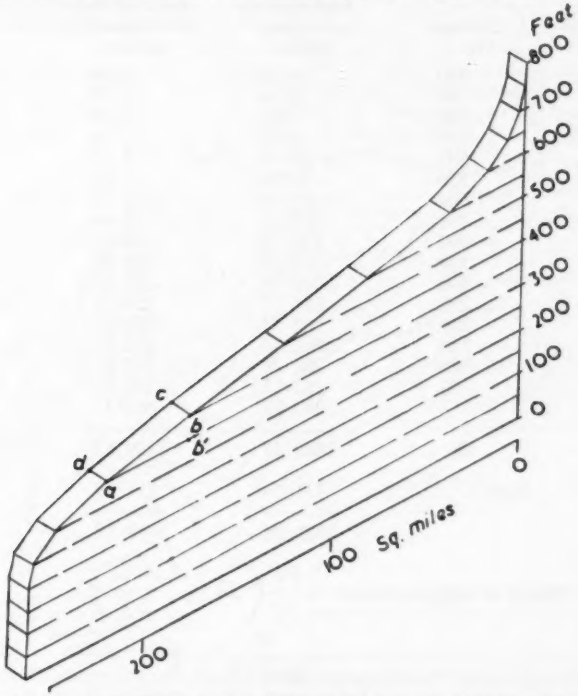
There is in fact no need actually to calculate the volume when the mean height is alone required. It is sufficient to sum the areas

enclosed by each contour,[1] subtract half the sum of the first and last areas, divide by the total area and multiply by the contour interval.

That is, the mean height of a planimetered area is given by

$$h = \frac{VI}{l_n}\left(\Sigma l - \frac{l_o + l_n}{2}\right)$$

The mean height of the actual surface and of the streamline surface having been determined, the difference gives the mean available relief.



TEXT-FIG. 2.—Arrangement of planimetric data in determining volume. The diagram is based on planimetry of the upper Cherwell basin.

To measure mean available relief alone, the arithmetic is still further reduced ; the required result is given by

$$r = \frac{VI}{l_n}\left(M_a - M_s\right)$$

where $M_a, M_s = \Sigma l - \dfrac{l_o + l_n}{2}$

for the actual and streamline surfaces respectively.

[1] I.e. for each contour, the whole of the area above it, not merely that area between the contour in question and the next highest.

By means of these simple calculations, which are illustrated below by data for part of the Cherwell and Glyme basins, it is possible to compare area with area in the following respects :—

1. Mean height of actual surface above sea-level.
2. Mean height of streamline surface above sea-level.
3. Mean available relief.

Contour, ft.	*Square Miles.* *Area enclosed on actual surface.*	*Area enclosed on streamline surface.*
800	0·00	0·00
750	0·30	0·00
700	3·09	1·18
650	9·01	3·14
600	19·53	6·57
550	38·94	13·82
500	81·26	27·34
450	127·17	52·04
400	176·24	94·86
350	218·60	150·82
300	246·71	222·17
250	259·77	255·78
200 [1]	262·37	262·37
150	262·37	262·37
100	262·37	262·37
50	262·37	262·37
0	262·37	262·37
Σl	2492·47	2139·57
Less $\frac{l_o + l_n}{2}$	131·19	131·19
	2361·28	2008·38

$$\text{Mean height of actual surface} = \frac{VI}{l_n}\left(\Sigma l - \frac{l_o + l_n}{2}\right)$$

$$= \frac{50}{262 \cdot 37} \times 2361 \cdot 28 \text{ ft.}$$

$$\simeq 450 \text{ feet.}$$

Similarly, mean height of streamline surface $\simeq$ 383 feet.

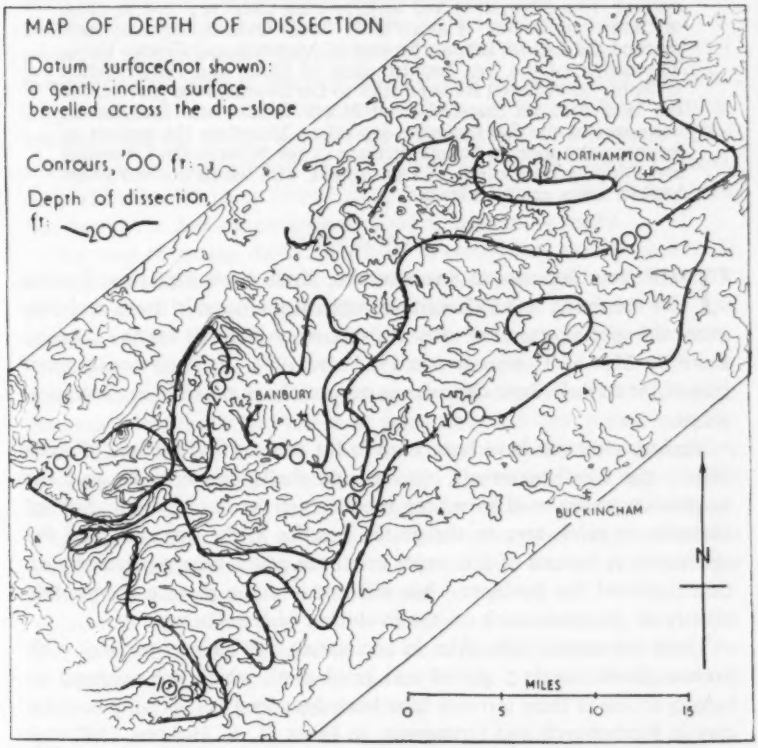
$\therefore$ Mean available relief $\simeq$ 67 feet.

Where a dissected erosional or structural surface can be clearly reconstructed the map of streamline surface contours can be used to give a measure of depth of dissection. A contour map of the reconstructed surface is drawn on a transparency and superimposed on the map of the streamline surface. Differences of height where the two sets of contours intersect are plotted, and isopleths drawn (Text-fig. 3). The resulting map shows the depth to which the main valleys have cut

[1] Planimetry was not carried below the 200-ft. contour.

below the reconstructed surface, which in Text-fig. 3 is the bevel truncating the Jurassic dip-slope.

It is possible by planimetry, using the techniques outlined above, to measure the volume between the actual and the reconstructed



TEXT-FIG. 3.—Isopleths of depth of dissection (heavy lines) superimposed on actual contours, in the Jurassic hill country between the Vale of Moreton and the upper Nene valley.

surface, or between the reconstructed and the streamline surface. Before such a measurement were undertaken, however, it should be certain that the reconstructed surface existed at one time in the form assumed. Such is not the case in the area here mapped.

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The Age of Interglacial Deposits at Swanscombe

By D. F. W. Baden-Powell

Abstract

The interglacial gravel at Swanscombe includes pebbles apparently derived from Shropshire and neighbouring districts ; and as some of these occur in the " Plateau Drift " near Oxford, they may have reached the Lower Thames by way of Moreton and Goring Gaps. The earlier of the two boulder clays of Essex and Hertfordshire probably contributed some erratics to the Swanscombe gravels, but the later includes material from North Britain and Scandinavia unknown in the Swanscombe deposits. Therefore the gravels at Swanscombe seem to be intermediate in age between the Lowestoft and Gipping Glaciations of East Anglia, with which the two Essex boulder clays are correlated.

Introduction

THE river deposits at Swanscombe, Kent, have long been famous for the fauna and Palaeolithic implements found in them, and they attracted special attention after the discovery of fossil human remains there by Mr. A. T. Marston in 1935 and 1936. It is obviously most important to date these deposits as accurately as possible in geological terms.

Various methods have been used in the past to find the age of these beds ; the fossil mammals, non-marine shells, implements, and the heights above sea-level have been used in turn for dating them. Special attention is given here to the glacial erratics in the deposits, and the references at the end of this paper are those which bear particularly on this aspect of the problem. No attempt is made to give a complete history of previous work on the evolution of the Thames.

There are several difficulties in correlating the Thames terraces with known glacial stages ; gravel and brick-earth which are assumed to belong to one of these terraces have been described as overlying boulder clay at Hornchurch and Upminster, in Essex (T. V. Holmes, 1892 and 1894, T. I. Pocock, 1903, and H. B. Woodward, 1903–4), and are often quoted as proving that they are later than boulder clay in Essex ; but no bones or implements have been reported from the gravel at Hornchurch, and the correlation of this with the beds at Swanscombe depends on its height at 100 feet O.D. On the other hand, Pocock (1903, p. 203) has suggested that these terrace deposits pass into or go below boulder clay in East Essex, and Gregory (1922) placed his " fluvio-glacial gravels " near the top of the succession in the same area ; also implements like those of Swanscombe (including a Clactonian III implement) were collected by H. G. O. Kendall near Hertford, from gravel below boulder clay (H. G. O. Kendall, 1917). Hazzledine Warren (1942) has also shown that supposed terrace gravels in the valley of the Roding are overlain by boulder clay. As a

third alternative an interglacial date for the Swanscombe deposits has been suggested by Dewey (1931, p. 152) and stressed by Oakley (1938, pp. 28 and 55) on the grounds that (1) these beds are believed to be later than a diversion of the Lower Thames by an early ice-sheet (Wooldridge, 1938, p. 39) ; (2) the contained fauna indicates temperate conditions, and (3) the formation of these temperate deposits was followed by a period of solifluxion and formation of Coombe Rock. The position of this interglacial stage in terms of the East Anglian glaciations had been suggested previously by King and Oakley (1936, p. 53) as coming between the two chalky boulder clays of Norfolk and Suffolk. This correlation has been confirmed by a comparison of the palaeoliths from Swanscombe with those from Hoxne and other sites ; but so far there has been little definite geological proof of contemporaneity.

One way of testing these apparently contradictory interpretations is to find out whether any erratics in the Swanscombe beds can be shown to be derived from any particular glacial deposits. Anyone who has tried to collect the rarer erratics from the Thames gravels will know what a slow and difficult task this is, but fortunately Mr. A. T. Marston has for some time past made an extensive collection of erratics from the Swanscombe gravels and has most generously put this collection at my disposal for study. Mr. H. J. Wilson has also kindly sent me erratics found by him at Swanscombe. I should like to take this opportunity of thanking them both for allowing me to work on their collections. I am also most grateful to Dr. K. P. Oakley for much help and advice on the Swanscombe deposits ; to Mr. C. D. Ovey for identifying foraminifera in an erratic of Carboniferous Limestone ; to Dr. Zb. L. Sujkowski for reporting on an erratic of radiolarian chert ; to Dr. K. S. Sandford for lending me his collection of erratics from the Oxford Drift for comparison ; and to Mr. A. G. Davis for identifying foraminifera in a Carboniferous chert.

The Erratics in the Swanscombe Gravels

The main sequence in the Swanscombe beds (K. P. Oakley, 1938, p. 21) is :—

Upper Gravel (and Hill-wash)
Upper Loam
Minor Solifluxion Stage (p. 27)
Middle Gravels and Sands
Lower Loam
Lower Gravel

Some contemporaneous erosion took place during the deposition of the Middle Gravels. The Upper Gravel consists of local material and no erratics from any distance have been reported from it. The

assemblage of erratics found in the Middle Gravels has been described as similar to that in the Lower Gravel (Dewey, 1924, pp. 91–6, and 1932, pp. 38–40, and Dines, 1938, p. 25), although Greensand chert was perhaps slightly rarer in the Middle Gravels than in the Lower Gravel. The erratics mentioned by Dewey are :—

Sarsens
Rounded flint pebbles (dark brownish-black outside)
London Clay Basement Bed
Bull-head Bed flints
Hertfordshire Puddingstone
Various coloured flints
Greensand chert
Quartzites
Vein quartz
Pink granite

Dines (1938, p. 25) has suggested that some of the quartzites were originally brought from the Midlands by the Lower Chalky Boulder Clay ice, and adds that a *Gryphaea* from the Middle Gravel might also have been derived from the same boulder clay. Chandler (1932, pp. 71–2) has recorded an albite-trachyte and a pyroxene-andesite from the Lower Gravel (at Rickson's pit), and Dr. Tyrrell, who examined these two specimens, thought they could be from the Scottish Old Red Sandstone. However, these two rocks occur together near Wellington, in Shropshire, and again further west, in North Wales, so that a derivation from the west is also possible, and is confirmed by other erratics found at Swanscombe.

The Lower and Middle Gravels are essentially flint gravel, and stones other than flint are so scarce that they can only be collected in large numbers after long and patient search. Dr. K. P. Oakley has kindly supplied the following note on the condition of the flints :—

" Flints in these gravels are basically pale grey to greyish black, but they have mostly been iron-stained to varying depth in shades of yellow or reddish brown. Fractured surfaces have not developed a true porous patina, but there is usually a surface intensification of the iron-staining. A high percentage of the flints show a broad banding and mottling, such as occurs in the local Bull Head Bed, at the base of the Thanet Sand, from which many of the nodules forming raw material for the palaeolithic industries were evidently derived. Occasionally areas of the greenish black cortex characteristic of Bull Head Bed nodules have remained on the broken flints."

The following list shows the rock fragments (apart from the more common types of flint) which have been identified from the present collections ; the specimens are in the University Museum, Oxford :—

	Lower Gravel	Middle Gravel
Tertiary		
Hertfordshire Puddingstone		×
? Sarsen		×
Shell-bed. Base of London Clay		×
Cretaceous		
Hard chalk	×	×
Dark brown flint	×	×
Jasperized flint	×	×
? Lower Greensand	×	×
Ferruginous sandstone	×	×
Radiolarian chert (described in Appendix)		×
Greensand chert	×	×
Jurassic		
Silicified *Isastraea oblonga* (Portlandian)		×
Shelly limestone (? Upper Purbeck)		×
Trias		
Gypsum (presumably Trias)	×	
Rounded quartzites (Bunter pebbles)	×	×
Rounded sandstone (Bunter pebbles)	×	×
Rounded vein quartz (Bunter pebbles)	×	×
Tourmaline Grit (Bunter pebbles)		×
Rounded purple quartz-porphyry (Bunter pebbles)		×
Carboniferous		
Millstone Grit (or ? Hartzhill Quartzite)	×	×
Silicified crinoidal limestone (cf. Carboniferous Limestone of Flintshire)		×
Porous silicified limestone		×
Black chert		×
Carboniferous Limestone		×
Banded chert with foraminifera		×
Old Red Sandstone		
White quartz conglomerate (or ? Carboniferous)		×
? *Cambrian*		
Dark red arkose (cf. Lickey Hills)	×	
Of Uncertain Age		
Hard ferruginous mudstone		×
Brown micaceous sandstone		×
Reddish-purple sandstone with clay pellets		×
Dark purplish-grey ferruginous micaceous sandstone		×
Igneous		
Pink granophyre (cf. Wrekin)	×	
Aplite	×	
Fine-grained metamorphosed and chloritized biotite granite (? West Longmynd conglomerate)	×	
Purple silicified tuffs (? Bunter pebbles)	×	×
Fine-grained amygdaloidal basalt	×	
Potash-syenite-porphyry		×
Soda-rhyolite (? Shropshire)		×
Metamorphic		
Schistose sandstone		×
Quartz-schist (? Rushton Schist, Shropshire)		×

The apparent differences between the Lower and Middle Gravels in this list can be ignored, as they are most marked among the rarest constituents only.

The ultimate parent-rocks of some of these erratics is fairly certain.

Erratics of Southern Origin.—Most of the Tertiary and Cretaceous rocks are fairly local, though the Greensand chert and other Lower Cretaceous types have had to cross the North Downs to get to Swanscombe ; the chert is especially of the southern type, and is most unlikely to have come from north of the Chilterns. According to Dr. Sujkowski the Cretaceous radiolarian chert is unknown in place in England, but occurs in France and elsewhere on the Continent (see Appendix).

Erratics of Western Origin.—The Bunter pebbles and, if traced correctly, the Upper Carboniferous grits, Lickey Hill arkose, Wrekin granophyre, ? the silicified tuffs, the amygdaloidal basalt, the rhyolite and the quartz schist, could all come from the Shropshire-Welsh border area ; but it must be emphasized that some of the rocks have not been identified in detail with parent rocks ; it is rather their assemblage which suggests this area as their ultimate source ; the tuffs might have come from the Berwyn Hills. The white quartzite conglomerate is not so easy to place ; a similar rock occurs both in the Upper Old Red Sandstone and in the Millstone Grit in the neighbourhood of Abergavenny ; it is not likely to be derived from the Longmyndian conglomerates. The most probable source of the Carboniferous Limestone and the silicified crinoidal limestone seems to be northern Flintshire, though derivation from Derbyshire cannot be ruled out. The syenite-porphyry has phenocrysts of orthoclase and pseudomorphs with outlines of hornblende, with a little porphyritic quartz. This erratic has not yet been traced to any definite parent-rock.

As already mentioned, it has been suggested that the andesite and albite-trachyte recorded by Chandler (1931) might have come from Scotland, but derivation from near Wellington, Shropshire, seems more probable when the assemblage which I have described is considered. If this conclusion is correct no rocks in the Swanscombe gravels have been proved so far to have come from an exclusively northern source.

The silicified Portlandian *Isastraea* is represented by two flakes collected by Mr. Marston, and now in the Geological Department at the British Museum (E. 1261 and R. 36105), and Dr. Oakley tells me that he believes the only known British occurrence of this chert is at Tisbury, in Wiltshire. One is tempted to suggest that if these are worked flakes, they might have been brought to Swanscombe by Palaeolithic man. Dr. Oakley also has a specimen of *Potamides* from the Lower Gravel, which he thinks is derived from the Blackheath Beds.

Date of Arrival of Erratics in the Thames Basin

Our knowledge of the erratics of the London Basin as a whole is now sufficient to enable us to date relatively the arrival of some assemblages of rock-types. There seem to have been three main stages of arrival :—

(1) Greensand chert is found in very early deposits up to about 600 feet on the dip slope of the Chilterns (Salter, 1905, p. 16), and is probably the only non-local type of rock present in this ancient Drift. This chert presumably came from the south and south-west by river action, and Salter was opposed to Prestwich's earlier ideas of a " Westleton " marine deposit. Wells and Wooldridge (1923, p. 249) consider this stage to be the beginning of the " Proto-Thames ". There is in general much confusion between this early Greensand chert stage and the next phase to be discussed (see Gregory, 1922, p. 36), but it agrees on the whole with the " Pebble Gravels " of the Survey (see Deeley, 1916, p. 63) and of later writers (e.g. Wooldridge, 1938, p. 627).

(2) Bunter Drift, accompanied by an interesting assemblage of rock-types, including :—

Red quartzite	Rhyolite
Jasperized flint	Soft green tuff
Radiolarian chert	White quartz conglomerate
Crinoidal chert	Bunter quartzites
Carboniferous chert	

These erratics were stated by Salter (1905, p. 23) to occur from about 600–300 feet on the Chilterns, and he traced them back from the London Basin through Goring Gap to the Oxford " Plateau Drift " and the Moreton Gap (p. 39), and their occurrence in the early drift near Oxford was later confirmed by Sandford (1929). These rocks are found derived in the gravels of the " Proto-Thames " in a general north-eastern direction from Marlow into Hertfordshire and Essex, and the Bunter pebbles are also found in the older boulder clay of Essex. Recent work has shown that the gravels in the Caversham Channel contain some erratics of this type, and no new kinds of foreign material had been introduced since the older Chiltern Drift (Treacher, Arkell, and Oakley, 1948, pp. 128–132). Gregory (1922, p. 32) has suggested that the rhyolites may have come from the Cambridge Greensand, and other geologists favour the Ardennes, but the Welsh Border seems to be a more likely area of derivation.

(3) A completely new suite of rocks, believed to have been brought from a northern direction, is obviously associated with the ice-front mapped by Deeley (1916, p. 58) from Buckingham to Chelmsford. The erratics include :—

Red Chalk (Norfolk or Lincolnshire)
Spilsby Sandstone (Lincolnshire)
Jurassic fossils and rocks from Lias to Purbeck

Among many igneous rocks :—

Augite-trachyte (cf. Fife)
Augite-granophyre, Dacite } (cf. Cheviot)
Cf. Eskdale Granite (Lake District)
Cf. Whin Sill (Northern England)
Laurvikite, Nepheline-syenite, Rhomb-porphyry } (Norway)
Olivine-basalt (cf. South Scotland)
Felsite (cf. Sweden)
Dolerite with porphyritic augite

Metamorphic :—

Granulite, Mica schist with garnet, Green Schist } (? Scottish Highlands)
Gneiss (? Norway)

Beds with these erratics have been seen at a number of places overlying the deposits of " Proto-Thames " type. In addition to these new arrivals, various rocks like Carboniferous Limestone, greenish rhyolite, radiolarian chert, jasperized flint, green tuff, and probable Charnwood rocks, may be considered as derived from the gravels of the " Proto-Thames " and other older deposits. This is a composite list from a number of localities, the chief of which are :—

Toddington and Leagrave, near Dunstable (Worthington Smith, 1894, p. 69) (Salter, 1905, pp. 20 and 22).

Finchley (Woodward and Goodchild, 1887 ; Humphreys, 1906).

Hertford and Ware (Barrow, 1909 and 1914, and Sherlock and Pocock, 1924).

Barkingside (Hinton, 1900).

Bishop's Stortford (Harmer, 1928, p. 128, and A. and P. A. Irving, 1914).

Felstead (Rowe, 1887).

I myself have found similar erratics of northern or north-eastern derivation from Buckingham to Leighton Buzzard. The marked difference between the contents of this drift and that of the earlier Bunter Drift has been stressed by Warren (1945, p. 273).

The Hertford-Essex Boulder Clays

A long time ago Hicks (1892, pp. 336–7) described two boulder clays at Finchley, the lower containing material from the Midlands and two boulder clays were also described along the Stort Valley (A. and P. A. Irving, 1913, p. 481), but these discoveries seem to have attracted little attention until Wells and Wooldridge described two

boulder clays in Essex, the older of which brought Bunter Drift " from the west or north-west " (1923, p. 250). It was pointed out that the normal drift from the north could not pick up Bunter pebbles direct because it crosses no Bunter outcrop and must be due to a later ice-sheet which picked up these erratics from the earlier Drift from the west. Soon after this, Sherlock described Lower and Upper boulder clays from Hertfordshire (Sherlock, 1924, p. 23). Sections have long been known showing two glacial deposits in superposition at Hertford and Ware. Incidentally, it seems probable that the relation of the two was also once visible at Tyttenhanger, south-east of St. Albans, but the sections there are now closed down (1950). Sherlock concluded that the Boyn Hill Terrace is slightly later than his Upper Boulder Clay (1924, p. 24), but this opinion took no account of the petrology of any of the deposits. It must be explained that it is not always easy to distinguish these two types of drift in the field, as the later has picked up much material from the earlier ; but in spite of this there is considerable evidence of two glacial episodes which also supports the westerly derivation of the early ice-sheet and the more northerly origin of the later one. The details which have been recorded of the sections near Hertford and Ware show, in fact, that the association of North British with Scandinavian rocks, seen typically at Finchley, were restricted to the upper part of the sections, whereas the " lower boulder clay " in several instances contained an assemblage of Bunter pebbles with Jurassic material, together with rocks of " Proto-Thames " type.

It is most important that these matters of detail should be confirmed by further field-observation ; but as evidence stands at present the " lower boulder clay " of Hertford and Essex contains material from the west which would have travelled on a course parallel to that of the movement of the Lowestoft (" Lower Chalky ") Boulder Clay of Norfolk and Suffolk, whereas the ice-movement from approximately north to south which supplied the material for the " upper boulder clay " of Hertford and Essex is a continuation of the direction of the Gipping (" Upper Chalky ") Drift of Suffolk. The arrival of Scottish with Scandinavian material during the Gipping glaciation in Suffolk (Baden-Powell, 1948) is therefore contemporaneous with the first appearance of the same material in Hertfordshire and Essex. If we are correct in referring the " lower boulder clay " of the London Basin to the Lowestoft glaciation of Suffolk, and the " upper boulder clay " to the Gipping glaciation, it should be easier now to date the stages of development of the Thames in terms of the East Anglian glacial stages.

The Age of the Swanscombe Deposits

It is most unfortunate that it is no longer possible to see the critical sections at Hornchurch and other places, but from the published

evidence the erratics from the lower boulder clay at Tyttenhanger, Ware, the Roding Valley, Hornchurch, and Upminster are of Lowestoft type, including in their material :—

Rounded flint pebbles	*Lucina minuscula*
Spondylus spinosus	*Perisphinctes biplex*
Hard chalk	Oxford Clay
Middle Chalk	*Gryphaea dilatata*
Lower Chalk	*Plesiosaurus* vertebra
Lower Greensand	Great Oolite rock
Various coloured flints	Lower Lias
Kimmeridge shale	Bunter quartzites

This is all that is known at present of the boulder clay on which the supposed terrace deposits rest in this area, and the absence of Scottish, Scandinavian, or North English erratics in this Bunter-Jurassic Drift may be very important for dating. The gravel observed by Hinton near Barkingside may perhaps be outwash from the later Gipping Boulder Clay near Bishop's Stortford, and it is suggested that it may not belong to the Boyn Hill Terrace, as mapped by the Geological Survey. Hazzledine Warren (1924, p. 8) says the supposed Terrace gravel below boulder clay in the Roding Valley does not contain erratics (presumably meaning that there are none of northern origin).

A comparison of the erratics recorded here from Swanscombe shows that they are derived from the Goring Gap type of Drift and probably also from the Lowestoft boulder clay, though this has not yet been proved definitely ; but the northern rocks typical of the Gipping glaciation are not found at Swanscombe. This is admittedly negative evidence, but as far as the erratics have been collected and identified, they support the idea that the Swanscombe gravels are pre-Gipping, and do not contradict the idea that the Swanscombe deposits come between the Lowestoft and Gipping Glaciations in age ; this is fully confirmed by the similarity of the implements from the Middle Gravel to those of Hoxne, and it is interesting to recall that northern rocks of Gipping type arrived at Hoxne in the gravel overlying the beds with twisted hand-axes and Clactonian III implements (Baden-Powell in Moir, 1935, p. 53). The pre-Gipping date of the Swanscombe deposits is thus proved by the available evidence of the erratics, but the relation of the Iver, Taplow, and Crayford gravels to the Gipping Glaciation still remains an unsolved problem. The evidence further north suggests that the Levalloisian industry started in force about the time of the Gipping Glaciation or just before it, as a tortoise-core has now been found associated with northern erratics in the Gipping Boulder Clay near March, in the Fen District (Baden-Powell, 1951, p. 38), and northern erratics were present with the Levalloisian at Brundon

(Baden-Powell, in Moir and Hopwood, 1939, pp. 29–30). Although detailed records of the erratics are scanty, there seems to be a strange lack of evidence for outwash gravels with the Gipping types of erratics outside the Leighton Buzzard, St. Albans, and Finchley lobes of this ice-sheet. This problem has been raised by Wooldridge (1938, p. 644), but he offered no petrological evidence for his correlations. It would be most interesting to see whether gravels which appear to be of Iver or Taplow date in the Colne and Lea Valleys contain such erratics. I know of no direct evidence on this question, but a boulder of hornblende schist has been found by Hazzledine Warren in the Flood Plain Gravel of the Lea Valley, and other rocks of this type may be found in the future in the Taplow Terrace along this valley.

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Appendix

A PEBBLE WITH RADIOLARIA FROM THE 100-FT. TERRACE AT SWANSCOMBE, KENT

By Zb. L. SUJKOWSKI

The pebble described in the present note was found by Mr. A. T. Marston in the "Silt layer" of the Middle Gravels in the 100-ft. terrace of the Thames at the Barnfield Pit, Swanscombe. It has been derived from a bed of calcareous chert containing radiolaria. It seems worthy of a brief description.

The rock is yellow-brownish in colour, dense and fairly homogeneous, with the exception of a small sponge (1 cm. diameter, probably one of the *Calcarea*) which has weathered differently, the spicular or

fibrous mesh having been replaced by compact limonite. Limonite is present throughout the rock also, but in fine dispersion. It is responsible for the present colour of the rock and is of double origin ; some, for instance, inside foraminifera, is probably a product of weathering of glauconite ; while the dispersed limonite and that in the interstices of the sponge may be after some other mineral, perhaps chlorite. Mineralogically the rock is mainly composed of fine fibres of chalcedony, calcareous matter and limonite being subsidiary components. The fibres of chalcedony have been formed either by recrystallization of silica in sponge spicules and radiolaria, or through siliceous replacement of calcareous cement and calcareous organisms. No detrital material is visible. Calcite occurs chiefly in the incompletely silicified skeletons of bryozoa, foraminifera, echinoderm fragments, etc.

From the point of view of the origin, the rock is composed of :—

Sponge spicules (chiefly tetractinellid, less numerous monactinellid types, forming nearly 25 per cent of the rock).

Bryozoa (up to 15 per cent of the rock, on a rough estimation, chiefly of the group Cyclostomata).

Foraminifera (up to 3 per cent, chiefly small but some large *Nodosaria*).

Radiolaria, sporadic (below 0·1 per cent of the rock).

Echinoderm remains, sporadic echinod spines.

Cement (slightly calcareous and argillaceous, chiefly siliceous, making more than 50 per cent of the rock).

The foraminifera include many species (cf. *Nodosaria*, cf. *Gumbellina*, etc.). Radiolaria are rather scarce ; all with the exception of one belong to *Spumellaria*. They are very well preserved, but in thin sections close determination is always difficult. It seems that some of them belong to the genus *Dicolocapsa* and one skeleton is near to *Dictyocephalus*. All the radiolaria are small, lightly built forms, with fine perforation, and probably all are planktonic, no bottom forms being observed.

None of the preserved fossils is strictly characteristic for stratigraphic purposes, but the general character of the rock suggests very strongly that it is Mesozoic, more precisely Upper Cretaceous.

I am not aware that any such rock has previously been described in Great Britain, but it is well known on the Continent. In France (1) such rocks are called *gaize*, characteristically composed of three recognizable components : sponge spicules forming more than 50 per cent of the rock, detrital material (sand grains), and remains of calcareous organisms. The subvariety of *gaize* which is devoid of detrital grains is called *smectique*. These rocks appear on more than one horizon in the Paris basin, but never in the centre, only on the

periphery. The best known is in the *Actinocamax quadratus* zone, the Nord Department, and around Hevre, on the Belgian side, where a deposit of this type occurs also in the *Inoceramus labiatus* zone, and in the Pays de Brie, in the *Schloenbachia inflata* zone. The same facies fringe the White Chalk in other parts of Europe : in North Germany (2), in Lower Senonian ; in Central Bohemia (3), in Upper Turonian ; in Poland, along the eastern slopes of the St. Cross Mountains, in the *Act. granulatus* and *quadratus* zones (4). Everywhere it contains sporadic but well-preserved radiolaria. Everywhere it seems to be developed between the neritic facies and the white chalk facies. (The *gaizes* are also known in the Oxfordian of France and Poland but they are quite different petrographically.)

If the pebble described above has been derived from rock anologous to *gaize*, as seems most likely, it may indicate that in England this facies existed as a fringe outside recent distribution of the White Chalk, and has been completely destroyed by denudation or hidden by drift. In this case, derived pebbles would be the only traces available at present.

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The Tyne Tunnel

By G. Armstrong and J. Kell [1]

Abstract

The following note refers to the geological features observed during the recent construction of tunnels under the River Tyne, with special reference to the relationship between the present and pre-Glacial courses of the river and the possibility of a Pleistocene (or later) beach level at 45 feet below O.D.

I. Introduction

THESE tunnels pass beneath the Tyne between Howdon, Northumberland, and Jarrow, Co. Durham, about 5 miles east of Newcastle and 4 miles from the mouth of the river, and form the first part of the Tyne Tunnel Project.

The work so far constructed consists of two parallel circular cast-iron lined tunnels, of 10 ft. 6 in. and 12 feet internal diameter, for the use of pedestrians and pedal cyclists respectively, and connected at each end to an inclined tunnel of 18 ft. 6 in. internal diameter equipped with twin escalators. There are also vertical lift-shafts with access passages leading into the pedestrians' tunnel.

A tunnel for vehicular traffic, which constitutes the main part of the project, is to be constructed at a future date. This tunnel, approximately 1 mile in length, will be of 29 ft. 3 in. internal diameter, and will also involve extensive approach works.

The present tunnels are about 1,200 feet long overall. The river at this point is about 800 feet wide, 600 feet of which is a navigable channel dredged to a depth of 30 feet below low water, the tidal range is 15 feet. The crown level in both the cyclists' and pedestrians' tunnels is approximately 30 feet below the bed of the dredged channel.

The driving of the tunnels was carried on from both sides of the river. All the work on the Northumberland side, including the sinking of the vertical shaft and inclined escalator tunnel, and the driving of the pedestrians' and cyclists' tunnels for two-thirds of the distance across the river, had to be carried out under compressed air in difficult water-bearing strata. During the under-river tunnelling air pressures ranging between 31–39 lb. per sq. in. were required in order to balance the hydrostatic head. On the Durham side ground conditions were sufficiently favourable to allow the shaft and escalator tunnel to be sunk by ordinary methods and the cyclists' and pedestrians' tunnels to be driven one-third of the distance across the river in rocks of the Upper Coal Measures, also without using compressed air.

[1] Published with permission of the Director, Geological Survey and Museum.

II. Geological Features

The country around Jarrow and Howdon is covered by a variable thickness of glacial deposits consisting of stiff grey boulder clay with irregular lenses and layers of sand and gravel. The underlying solid rocks form part of the Upper Group of the Coal Measures and are made up of sandstones and shales with infrequent coal seams and their attendant seat-earths. Some of these coal seams attain a thickness of 3 feet, but none have been worked.

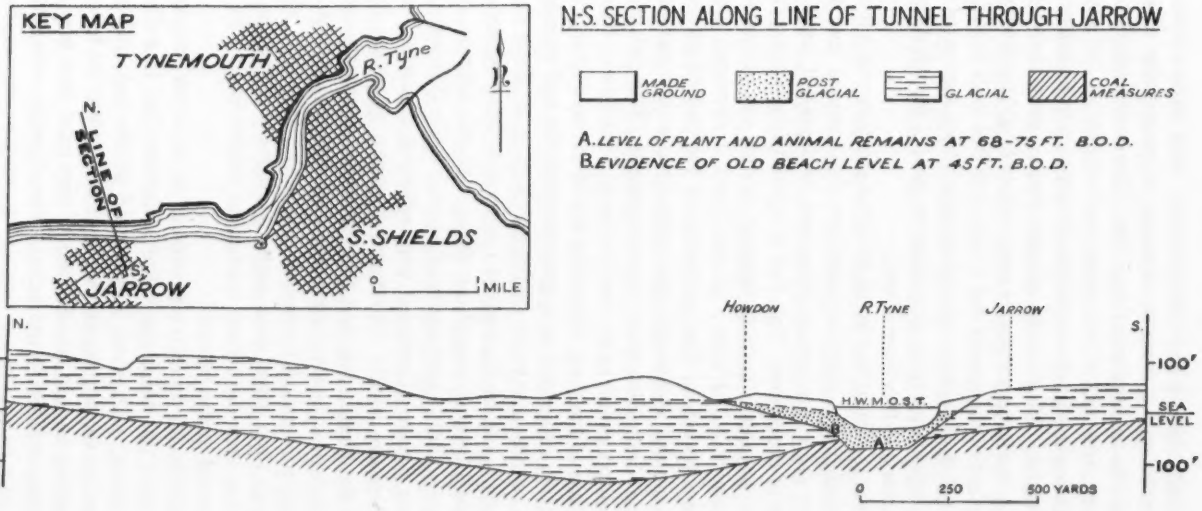
As long ago as 1820, however, the uppermost seam of the Middle Coal Group, namely the High Main Seam, was extensively worked throughout the area. This seam lies at a depth of about 750 feet and is usually about 6 feet thick. The workings in this seam revealed that beneath Jarrow and Howdon the Coal Measures had been dislocated by many small-throw faults, usually trending in a N.N.W.–S.S.E. direction. These faults cause variation in the local dip of the strata, but the regional strike is N.W.–S.E., with the beds rising gradually to both the N.E. and S.W., Jarrow being situated on the deepest part of the broad Boldon–Hylton syncline.

In all some twenty-four bore-holes were sunk from the surface to test the ground along the line of the main tunnel, both to the north and south of the river, and two bore-holes were sunk from the base of the pedestrian tunnel, beneath the river bed. The information from these and other bore-holes, together with that from the shafts on the river banks and the tunnel drivages, shows that the solid rock surface beneath the superficial deposits, slopes downwards to the north. The rockhead is deepest (about 140 feet below O.D.) at some point about one-third of a mile north of the present course of the river, and it is considered that this position represents the centre of the pre-Glacial valley of the Tyne.

The post-Glacial Tyne has cut through the glacial deposits to notch the rising rock slope (at 82 feet below O.D.) forming the southern side of the pre-Glacial valley, and has deposited the post-Glacial material encountered in the shafts and the tunnels. A generalized section of the formations encountered is as follows :—

North Bank.	*Tunnel.*	*South Bank.*
Post Glacial deposits	Post Glacial deposits	—
Glacial deposits	—	Glacial deposits
Coal measures	Coal measures	Coal measures

The general relationship of the Coal Measures and the overlying Glacial and post-Glacial deposits can be seen from the diagram. The Glacial deposits consist of sand and gravel overlain by boulder clay. At the base of the Glacial deposit is a 4-ft. bed of fine to medium gravel, sometimes clean but often heavily iron-stained, in beds of erratic thickness and inclination. This is overlain by about 12 feet of very fine,


KEY MAP
TYNEMOUTH
R. Tyne
N.
LINE OF SECTION
S.
S. SHIELDS
JARROW
0
1 MILE
N:S. SECTION ALONG LINE OF TUNNEL THROUGH JARROW
MADE GROUND
POST GLACIAL
GLACIAL
COAL MEASURES
A. LEVEL OF PLANT AND ANIMAL REMAINS AT 68-75 FT. B.O.D.
B. EVIDENCE OF OLD BEACH LEVEL AT 45 FT. B.O.D.
HOWDON
R. TYNE
JARROW
N.
S.
100'
SEA LEVEL
100'
H.W.M.O.S.T.
A
B
100'
SEA LEVEL
100'
0
250
500 YARDS

compact, light brown sand containing a high proportion of loamy material. Above is a variable thickness of glacial clay which can be subdivided into a lower and upper bed. The lower bed is about 8 feet thick at the north end of the tunnel, and consists of stiff grey boulder clay containing unsorted material of all sizes up to boulders of several hundredweights. Much of this smaller stony material consists of shale fragments ; the larger stones are mostly from Coal Measure sandstones. The upper bed of the glacial clay is about 28 feet thick at the south end of the tunnel, and is made up of fine dark brown laminated clay, with numerous minute partings of micaceous sand ; the whole bed is very homogeneous and free from stones.

The top of the lower bed in the Howdon escalator shaft is marked by a covering of brown silty clay with very fine laminae, and appears to be derived from the glacial clay and re-deposited under tranquil conditions of deposition. This bed of layered clay is only a few inches thick, and no clear junction between it and the underlying glacial boulder clay could be seen ; at one point it appeared that the one merged into the other. Resting on top of the layered clay is a bed of fairly fine-grained incoherent sand with occasional irregular silty and loamy bands containing many plant fragments. These plant fragments include well-preserved hazel nuts and twigs from rowan trees.

At the base of the sand, resting on top of the layered clay and sometimes partially embedded in it, are numerous flat and rounded pebbles and small boulders up to 10 centimetres across, to which are attached small fragile barnacles such as are common on shells adhering to piles and uprights for piers round our coast. At this junction, which is at 45 feet below O.D., many shells of *Mytilus edulis* (Linnaeus), and one of *Littorina littorea* (Linnaeus) with adherent barnacles were found. Both species are widely distributed common shoreline forms, well known in the Pleistocene, and their presence, apparently untravelled, probably indicates the low-tide mark of a former beach level. Scattered shells of *Mytilus* and *Littorina* were found in the sand overlying the boulder clay, but they were without adherent barnacles, and this suggests that they have been washed to deeper water, the barnacles being removed in the process.

The post-Glacial deposits encountered in the tunnel drivages rest on rocks of the Coal Measures. The lowermost bed is a clean fine to medium gravel, with some coarse sand at the top, and grading to coarse open gravel with occasional large boulders at the bottom. Most of the boulders are sub-angular and of very hard dark grey limestone. Many pebbles of hard sandstone and some of granite were also observed. Rounded coal fragments are present. Resting on this sand and gravel deposit, and overlapping on to the Coal Measures toward the north bank of the river is a bed of dark grey, compact, consolidated silt, with

a small content of fine sand. In places this bed is thickly impregnated with vegetable debris in small fragments of bark, twigs, and hazel nuts, and scattered portions of the trunks and large branches of rowan trees were found.

At about the junction of the silt and the underlying sand and gravel the following identified animal remains were found :—

(1) Part of right antler of elk, *Alces machlis* Ogilby, in silt, 67 feet below O.D.

(2) The sixth cervical vertebra of *Cervus* intermediate between *C. giganteus* (Blumenbach) and *C. canadensis* Illiger, in sand, 68 feet below O.D.

(3) The fourth or fifth lumbar vertebra of *Bos*, in sand, 69 feet below O.D. Dr. Hopwood, of the British Museum, suggests that the unmineralized condition of this bone probably indicates at the earliest a very late Pleistocene Age.

(4) The right femur and tibia of *Bos primigenius* Bojanus, in gravel, 74 feet below O.D.

The third post-Glacial deposit encountered in the tunnel drivages overlaps on to the two beds described above, and consists of river sand with irregular bands and pockets of silt.

Conclusions

It is considered that only large-scale variations in sea-level can explain the difference between the present sea-level, the depth of the pre-Glacial valley of the Tyne at 140 feet below O.D., and the depth of rockhead beneath the present channel at 82 feet below O.D. It also seems probable, on the evidence of the shells, apparently in situ at 45 feet below O.D., that a beach existed at this level at some period later than early Pleistocene times.

Acknowledgments are due to Dr. Blackburn, of the Botany Department, King's College, Newcastle-upon-Tyne, who examined some of the plant remains, to Dr. Stubblefield of H.M. Geological Survey, and to Dr. Hopwood, of the British Museum, who identified the animal remains.

The Lamellibranch Genus *Schizodus* and Other Palaeozoic Myophoriidae

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ABSTRACT

The paper records the characters of the genus *Schizodus* as defined by its type-species *Axinus obscurus*, and shows that King's reconstruction of the hinge-characters of *Schizodus truncatus*, regarded by him and many subsequent authors as the type-species, was inaccurate. The conclusion is reached that *Protoschizodus* de Koninck and the forgotten genus *Prisconaia* Conrad should be regarded as synonyms of *Schizodus*. A new generic name *Eoschizodus* is proposed for those smooth Myophoriidae of the Devonian, Carboniferous and Permian which differ from *Schizodus* in possessing the full number of hinge-teeth for the family, but which lack the conspicuous anterior myophorous buttresses of the Triassic *Neoschizodus*.

INTRODUCTION

MOST authors, following King (1850, p. 185) have regarded the English Permian species *Schizodus truncatus* as type-species of *Schizodus*, and King's (1850, pl. 15, fig. 29) reconstruction of the dentition of this species has been accepted without question, his figures being reproduced in several later monographs and standard textbooks. The most notable feature indicated in these figures is the prominent, deeply cleft median tooth of the left valve ; this, in fact, led to King's choice of the generic name. A comparable feature is found in the restricted family Trigoniidae,[1] which appears first in the Upper Trias. *Schizodus* has, therefore, been regarded by some authorities (Frech, 1889 ; Wöhrmann, 1893) as an offshoot from the smooth Myophoriidae which is confined to the Permian and remarkable for the precocious appearance of this strongly bifid tooth. As Nicol (1944), however, has shown, King was anticipated by de Verneuil and Murchison (1844) in the valid publication of the generic name. Of the several species included by these authors in the genus, the well-known Permian form *Axinus obscurus* J. Sowerby was the first to be cited as type (de Verneuil, 1845). *S. truncatus* remained a *nomen nudum* until 1848. *Axinus obscurus* must, therefore, be accepted as type-species of *Schizodus* and form the basis for the interpretation of the characters of the genus. In any case, as will be seen later, King's description and figures of the hinge-characters of *S. truncatus* were inaccurate.

[1] It is proposed to divide the Trigoniidae of earlier authors, now to form a Superfamily Trigoniacea co-extensive with an Order Schizodontida, into two families, Myophoriidae and Trigoniidae, the latter to include the numerous groups united by earlier authors in a single genus *Trigonia*.

THE CHARACTERS OF SCHIZODUS OBSCURUS (J. Sowerby)

Although this is one of the commonest species of the marine Permian of northern Europe, specimens retaining the original shell well enough preserved to allow the hinge-teeth to be developed have yet to be collected. In England, Germany and Russia alike the species occurs most commonly in the form of internal moulds of closed bivalve shells, although imperfect specimens retaining a certain amount of shell may sometimes be found. It has, therefore, been necessary to reconstruct the characters of the hinge from such material. The best preserved internal moulds examined come from the German Permian. The account here given is based largely on a specimen (Brit. Mus., Geol. Dept., 63526) from the Zechstein Dolomite of Rückingen, near Hanau. The impressions of the main teeth are well preserved, and gelatine " squeezes " reproduce the original form of the teeth quite clearly. An internal mould with displaced valves from the Lower Magnesian Limestone of Garforth, near Leeds, belonging to the Sedgwick Museum, has also yielded a " squeeze " reproducing the main tooth of the left valve.

A strong tooth is present just below the umbo in each valve. According to the notation most commonly accepted for the Trigoniacea [1] that of the right valve is identifiable as 3*a*, and that of the left as 2*b* ; when the two valves are in juxtaposition 2*b* lies behind 3*a*. The tooth 2*b* is stout and prominent in *S. obscurus*, ending distally in two rounded lobes which lie somewhat athwart, the posterior one occupying a more dorsal position. Tooth 3*a* forms a sharply pointed, thorn-like projection, almost as prominent as 2*b*, but not so stout.

In most Trigoniacea there is a second tooth (3*b*) in the right valve, and two further teeth (4*a*, 4*b*) are found in the left. 3*b* is usually weaker and more elongate than 3*a*, adjoining the postero-dorsal margin ; 4*a* is weaker than 2*b* and of no greater length, adjoining the antero-dorsal margin ; 4*b* is weak and elongate. In the German internal mould of *S. obscurus* and in one from the Upper Magnesian Limestone of Silksworth, Durham, lent to me by Dr. C. T. Trechmann, a small indentation along the dorsal margin, in front of the deep pit representing 3*a*, indicates the former presence of a small tooth 4*a* ; the impression of such a tooth is not, however, preserved in the Sedgwick Museum specimen. No trace of the posterior teeth 3*b* or 4*b* can be seen on any of the moulds examined. Mr. R. Casey has very kindly ground down specimens in which the actual shell was partly preserved in an attempt to detect these teeth. It seems certain that 3*b* is absent in the right valve, while 4*b*, if present at all in the left, must be very weak. *Schizodus* s. str. is, therefore, characterized by the reduction of the

[1] Odhner (1918) has suggested an alternative interpretation, which cannot here be discussed.

series of hinge-teeth normally found in the Trigoniacea to a single strong sub-umbonal tooth in the right valve and a strong bilobed, but not deeply bifid, sub-umbonal tooth in the left, with a weak tooth in front of it. In the type-species the umbones are opisthogyrous, but this does not seem to be a character of generic importance. There is no trace of the anterior myophorous buttresses which are so well developed in the Triassic Myophoriids and in all the Trigoniidae. On the other hand, one or sometimes two narrow depressions of the flank of the internal mould, representing ridges on the interior of the shell, descend posteriorly from the umbo in each valve.

The Characters of *Schizodus truncatus* King

The two figures in which King attempted to reconstruct the hinge of this species lie between figs. 30 and 31 of his plate 15. Their degree of enlargement is not stated, and it seems usually to have been assumed that they are of natural size. Professor J. Mitchell has very kindly lent me the original specimens, preserved in University College, Galway, used by King in making these reconstructions. The specimens are moulds of single valves from the Magnesian Limestone of Humbleton, Durham, and King's gutta-percha "squeezes" of their hinge-region, now much perished, are preserved with them. Similar "squeezes" have been prepared in plasticine for study.

The teeth all prove to have been extremely small, King's reconstructions being enlarged three or four times. The hinge of the right valve is represented with moderate accuracy in his lower figure. There is a projecting, simple tooth in a median position, and a thin, elongate tooth on its posterior side, with a recess between it and the margin, which it curves round to join. On the other hand, the reconstruction of the hinge of the left valve given in King's lower figure is most inaccurate. A small tooth occupies a median position, but it has not the deeply bifid structure depicted by King. This tooth has a short posterior branch in alignment with, but demarcated by a depression from, a thin lamellar tooth which is not radially disposed, but curves round to join the margin. On the anterior side of the median tooth is a small tuberculiform tooth projecting from the margin.

Although this species has the same number of teeth as a typical member of the Trigoniacea, their small size and the fact that they do not diverge radially from below the umbones suggest that we may be dealing with a representative of a different superfamily. It is, at least, evident that King's interpretation of the hinge-characters of *S. truncatus* and his definition of the characters of *Schizodus* were largely the product of imagination.

The Genus *Protoschizodus* de Koninck

The generic name *Protoschizodus* has been used for a group of Carboniferous species the dentition of which is described thus by Hind (1898, p. 226), mainly following de Koninck (1885, p. 125). "The left valve with two teeth situated anteriorly, the posterior and larger and most prominent being immediately below the umbo. The right valve has a single tooth situated in front, with a fossa on each side to receive the teeth of the left valve." If this description is compared with that of the dentition of *Schizodus obscurus* given above, it may be seen that the chief difference is the bilobation of the main tooth of the left valve of *S. obscurus*. The difference seems unimportant, especially as such bilobation is easily overlooked in imperfect material.

There are further reasons why the suppression of the name *Protoschizodus* seems desirable. De Koninck (1885, p. 125) proposed this name as a substitute for the lamellibranch generic name *Niobe*, of which there was more than one prior use in other animal groups. The type-species of *Protoschizodus* must, therefore, be selected from the genosyntypes of *Niobe*. This name was first applied to a genus of lamellibranchs in a catalogue of Belgian fossils compiled by Dewalque (1868, p. 329),[1] which formed a pre-issue of a chapter of a projected (but eventually unpublished) work to be entitled *Prodrome d'une description géologique de la Belgique*. This catalogue included the three names *Niobe fragilis* McCoy, *Niobe obliqua* McCoy, and *Niobe subtruncata* McCoy, but as these were unaccompanied by bibliographical references or any indication of the genera from which they had been transferred, *Niobe* must here rank as a *nomen nudum*. It was published by de Koninck five years later (1873, p. 77), this time accompanied by a generic diagnosis, by descriptions of the three species *N. luciniformis* sp. nov., *N. nuculoides* (McCoy, 1844, *Axinus*), and *N. elongata* sp. nov., all from the Carboniferous of Carinthia, and by a reference to "*Niobe* (*Axinus*) *obovata* McCoy". Hence the type-species of *Niobe* must be selected from these four species. All are relatively small forms, and the hinge-structure of only one (*nuculoides* McCoy) is at present known, and that imperfectly (Hind, 1898, p. 244). In the circumstances it seems advisable to refrain from deciding which shall serve as type. It is probable that the numerous Belgian Carboniferous species described under *Protoschizodus* in de Koninck's larger monograph (1885) belonged to more than one genus and family. His generic diagnosis was based on certain of the larger forms, and if the genus is

[1] What was probably the same catalogue also appeared in 1868 in the 8th edition of Omalius d'Halloy's *Précis élémentaire de géologie*. This work is not available in England.

provisionally interpreted by this diagnosis it may be seen that it should be relegated to the synonymy of *Schizodus*.

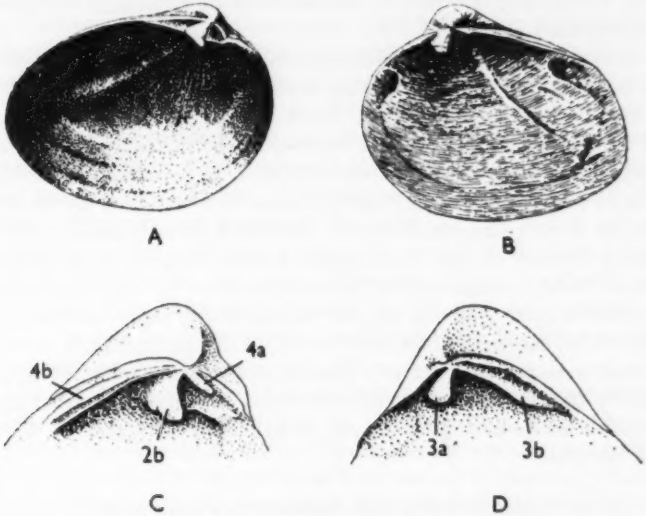
The Genus Prisconaia Conrad

Conrad (1867, p. 10) founded a genus *Prisconaia* on the species *P. ventricosa* Conrad, known to him only by a left valve from " Little Stranger Creek, ten miles from Fort Leavenworth, Kansas ". Dr. N. D. Newell has very kindly informed me that the rock formations exposed along this creek belong to the Lansing group of the upper part of the Pennsylvanian, and that it is possible that the type of *P. ventricosa* came from the subdivision known as the Vilas shale. Conrad's description and figure indicate that this left valve had a broadly triangular median tooth and a small, compressed tooth anterior to it. The anterior adductor scar lay very close to the latter tooth. The hinge depicted is clearly that of a Myophoriid, but the right valve, unfortunately, was not available for description.

The genus *Prisconaia* and the species *P. ventricosa* have been ignored by later workers on the Carboniferous palaeontology of this area. In Beede's work (1900) on the Carboniferous invertebrates of Kansas there are, however, illustrations (pl. 22, figs. 2–2*d*) of a specimen from the Upper Coal Measures of Lansing, Kansas City, identified as *Schizodus hari* Miller. The resemblance to Conrad's figure of *P. ventricosa* is so close that it seems most probable that the species is the same. Dr. Newell informs me that *S. hari* is a common fossil of the argillaceous shales of the Lane formation of the Kansas City group at Kansas City, and that this horizon is not far removed from the probable horizon of *P. ventricosa*. The type-specimen of *P. ventricosa* has not yet been located. It seems reasonable, however, to interpret the genus *Prisconaia* by the probably synonymous species *S. hari*, the interior of the left valve of which was illustrated by Miller (1892, pl. 20, fig. 1), and of the right valve by Beede (1900, pl. 22, fig. 2*d*). Hind (1898, pl. 16, fig. 1*a*) has also figured the hinge of a left valve of this species.

The hinge-structure of *S. hari* is almost identical with that of *Schizodus obscurus*, described above. In the left valve there is a very stout median tooth (2*b*) which is shown to be bilobed in Hind's figure but not in that of Miller, and a small tooth (4*a*) adjacent to the anterior dorsal margin ; a posterior tooth (4*b*) cannot be distinguished. In Hind's figured specimen, now in the British Museum (Natural History), 2*b* is quite distinctly bilobed, although more broadly so than the figure suggests. In the right valve of *S. hari* there is, according to Beede, a strong tooth 3*a* and, behind the socket which received 2*b*, " a slight sharp elevation extending obliquely backward," probably to be interpreted as an almost obsolete 3*b*. There is little difference between

this condition and that of *S. obscurus*, in which 3*b* seems to be quite obsolete, and, since both *S. hari* and *S. obscurus* lack any trace of myophorous buttresses and have a similar narrow internal depression descending posteriorly from the umbo in each valve, I consider that *Prisconaia* should be regarded as another synonym of *Schizodus*.



TEXT-FIG. 1.—*Schizodus* and *Eoschizodus*.

A. *Schizodus hari* Miller. Interior of left valve (× 0·68) from the Upper Carboniferous of Kansas City (after Miller). The bilobate character of the main tooth is not shown.

B. Same species. Interior of right valve (× 0·76) from the Upper Carboniferous of Lansing, Kansas City (after Beede).

C. *Eoschizodus* (n. gen.) *truncatus* (Goldfuss). Hinge region of left valve (× 1·5). Middle Devonian, Givetian, *Stringocephalus* limestone, of Paffrath, Germany (after Beushausen, slightly modified according to Goldfuss' illustration to show adductor scar).

D. Same species. Hinge region of right valve (× 1·2). Same formation and locality (after Beushausen).

As specimens of *S. obscurus* suitable for illustration of the hinge-characters are unobtainable, published figures of the interior of the two valves of *S. hari* are now reproduced in text-figure 1 (A, B) to show the characters of *Schizodus* as now interpreted.

THE GENUS TOECHOMYA CLARKE

Clarke (1899, p. 96), working at Devonian fossils from Brazil, considered that two of the species studied, although known only as internal moulds, had essentially the same characters as the German Devonian species *Schizodus transversus* Beushausen (1884, p. 95, pl. 5,

fig. 18), of which he possessed well-preserved internal moulds, collected on an excursion with Beushausen. He was able to prepare artificial casts reproducing the original hinge-structure of the German species, and found that this differed materially from that of *Schizodus*, as defined by King, and of *Myophoria*. He therefore proposed the new genus *Toechomya*, of which *S. transversus* is now formally designated as type-species.

I have not been able to obtain a specimen of *S. transversus* for study and must rely on Clarke's reconstruction of the hinge (1899, p. 101, text-figs.), although this is not above suspicion. A hinge-plate is said to be present in both valves. In the left valve 2*b* is simple, narrowly triangular, directed forward, and separated by a broad socket from a thin 4*a* ; 4*b* is weak and elongate ; below 4*a* is a socket. In the right valve 3*a* is well developed, and is separated by a triangular socket from an elongate 3*b* and by a furrow from a thin, marginal anterior cardinal tooth, presumably to be interpreted as 5*a*. Well separated from this is quite a strong anterior lateral tooth, which was received in the socket below 4*a* in the other valve. If this description is correct, *Toechomya transversa* is clearly distinguishable from other Myophoriidae by the presence of the anterior lateral tooth and of the hinge-plate, and the generic name cannot be employed for species in which these are absent.

Other Unornamented Myophoriidae of the Palaeozoic

While it thus appears that *Schizodus*, *Protoschizodus* and *Prisconaia* have essentially the same hinge-structure, characterized by the reduction of the dentition of the right valve virtually to a single tooth, and *Toechomya* has an altogether abnormal hinge for the family, there are many unornamented Palaeozoic species with a fully developed and normal Myophoriid hinge. Such forms are abundant in the Devonian, but seem to be rather less frequent in the Carboniferous and Permian. One of the best known is the German Devonian species originally described by Goldfuss as *Megalodus truncatus*. Its hinge-structure has been well illustrated by Goldfuss (1837, pl. 132, figs. 10), Gruenewaldt (1851, pl. 10, figs. 6), Frech (1889, pl. 11, fig. 4), and Beushausen (1895, pl. 9, figs. 13*a*–*c*). In the right valve a posterior tooth 3*b* is well developed in addition to 3*a*, and in the left valve there is a corresponding tooth 4*b*. Tooth 2*b* is weakly bilobed ; in other Devonian species also, according to Beushausen, it has an incipient bifid structure. The dentition, in fact, is almost identical with that of Triassic Myophoriidae, and German authors, including Beushausen, have referred these forms to *Myophoria*. They lack, however, the well-developed anterior myophorous buttresses found in the Triassic species, although in " *Megalodus* " *truncatus*, according to Beushausen,

there are traces of rudimentary buttresses (cf. Gruenewaldt, 1851, pl. 10, figs. 6). The type of *Myophoria*, moreover, is the Triassic species *M. vulgaris* (Schlotheim), in which a strong radial costa ornaments the flank of the shell ; unornamented Triassic forms are better included in the genus *Neoschizodus* Giebel. The absence or obscureness of the myophorous buttresses justifies the separation of the Devonian forms from this genus. Some of these species were included in the imperfectly defined *Curtonotus* Jukes, 1863, in any case a homonym of *Curtonotus* Stephens, 1827. The next name proposed for a member of the group, *Kefersteinia* Neumayr (1891, p. 788, type " *Megalodus* " *truncatus* Goldfuss), is a homonym of *Kefersteinia* Quatrefages, 1865. *Rhenania* Waagen, 1907 (type, now designated, *Myophoria schwelmensis* Beushausen), and *Hefteria* Lahmer, 1948 (type, original designation, *Cardinia carinata* Roemer) are groups of Devonian Myophoriidae with distinctive shape and ornament, and deserve generic distinction from the unornamented forms now under discussion. The new generic name *Eoschizodus* (type, *Megalodus truncatus* Goldfuss) is now proposed for these to replace the preoccupied name *Kefersteinia*. The hinge-structure is represented in text-figure 1 (C, D).

The internal characters of few of the Carboniferous and Permian species which have been referred to *Schizodus* have been adequately described and illustrated. Some of these species, however, undoubtedly have a more fully developed hinge than that of *S. obscurus*, described above. A crushed left valve from the Upper Magnesian Limestone of Blackhall Rocks, Durham, identified as *S. schlotheimi* Geinitz and kindly lent to me by Dr. C. T. Trechmann, shows that 4*a* as well as 2*b* is well developed, but the presence of 4*b* is doubtful. In the American Permian species *S. oklahomensis* Beede, described by Newell (1940, p. 291, pl. 1, figs. 1–6) and by Roth, Newell, and Burma (1941, p. 316, pl. 45, figs. 1–9), two teeth (3*a*, 3*b*) are strongly developed in the right valve, 3*a* being bilobed—an unusual feature in the family. In the left valve 2*b* is strong and bilobed and 4*a* is well developed, but 4*b* becomes obsolete during growth ; myophorous buttresses are weakly developed. In *S. pinguis* Waagen (1887, p. 236, pl. 19, figs. 7–10), from the Permian of the Salt Range, 3*b* and 4*a* are well developed, there are traces of 4*b*, and 2*b* is " indistinctly bifid ". It is suggested that species such as the last two are best regarded as survivors of *Eoschizodus*.

ACKNOWLEDGMENTS

I must express my thanks to Professor J. Mitchell, of University College, Galway, Eire, for the loan of King's original specimens of *Schizodus truncatus* ; to Mr. C. E. Fisher, B.Sc., Curator of the Hancock Museum, Newcastle-upon-Tyne, and Dr. C. T. Trechmann,

for looking out and sending me specimens for examination ; and to Dr. C. J. Stubblefield, F.R.S., and Mr. A. G. Brighton, for giving me facilities to examine specimens in the Geological Survey and Sedgwick Museums respectively. I am indebted to Dr. N. D. Newell, of the American Museum of Natural History, for information about the type-locality of *Prisconaia ventricosa*. I must particularly thank Mr. R. Casey, of the Geological Survey, and Mr. L. E. Parsons, of the British Museum (Natural History), for their skilled assistance in investigating the hinge-structure of a number of specimens.

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CORRESPONDENCE

TYPE SPECIES OF THE OSTRACOD *RHOMBINA*

SIR,—In my paper on the *Rhombinidae* (*Geol. Mag.*, xxxviii, 209–212), I overlooked the fact that the type-species of the ostracod *Rhombina* had already been designated by Bassler and Kellett (1934, *Geol. Soc. Amer., Sp. Paper* No. 1) as *R. hibernica*. This has priority, therefore, over the species (*R. belgica*) selected by me.

As explained in the paper, I consider that *R. belgica* and *R. hibernica* are certainly congeneric and perhaps synonymous, so no new interpretation of the genus is necessary on account of my error.

P. C. SYLVESTER BRADLEY.

DEPARTMENT OF GEOLOGY,
ST. GEORGE'S SQUARE,
SHEFFIELD 1.
8th August, 1951.

THE MOINE SCHISTS

SIR,—Recent papers on the proposed Moine-Torridonian correlation appear to have overlooked Professor J. G. C. Anderson's identification of Moinian granulites in the core of the Lough Derg anticline (S. Donegal), surrounded by the Dalradian sequence. If this be accepted—and it is difficult to challenge it—some at least of the Scottish Moines cannot be of Torridonian age. The problem is thus not so much whether Horne or Peach was right, as the difficult one of distinguishing between Moine and Torridonian in various degrees of metamorphism. The Torridonian has not so far been positively identified in the north of Ireland ; but in my view, the conglomerate which occurs as a faulted inlier on the west side of Lough Swilly, near Portsalon, is much more probably Torridonian than Old Red Sandstone as mapped by the original Survey of Ireland. It lies some 40 miles north-east of the Lough Derg anticline and perhaps 60 miles south-west of the nearest Torridonian in Islay.

D. W. BISHOPP

GOVERNMENT OF CYPRUS,
OFFICE OF THE SENIOR GEOLOGIST,
CYPRUS.
10th September, 1951.

REVIEWS

PALÉONTOLOGIE : Colloques Internationaux du Centre National de la Recherche Scientifique. xxi + 256 pp. (sm. 8vo). Paris, 1950. Price 390 francs. (London : H. K. Lewis and Co.)

The same team that represented British Palaeontology at the International Conference on Genetics, Palaeontology, and Evolution at Princeton in January, 1947, took part in an International " Colloquium " at Paris in April of that year. The former gathering resulted in the well-known *Genetics, Paleontology and Evolution* (Princeton University Press, 1949), and the latter in this more moderately-priced report entitled *Paléontologie*, to which D. M. S. Watson communicates an article on the Evolution of the Amphibia, J. B. S. Haldane on the Mechanisms of Evolution, and T. S. Westoll contributes to many of the discussions. Haldane's confidently materialistic account is followed by a persuasive rejoinder from P. Grassé under the same title, outlining some of the difficulties in the neo-Darwinian interpretation. C. Arambourg supplies an interesting essay on Extinction and in this, as in G. G. Simpson's discussion of Orthogenesis, examples are noted from the realm of invertebrate palaeontology ; but it is perhaps a legitimate criticism of this as of the Princeton publication that the term " palaeontology " tends to be used in the more limited sense of " vertebrate palaeontology ". E. A. Stensiö's admirable anatomical account of the labyrinth cavity and orbit of *Jagorina* seems curiously out of place here, but the volume (which is excellent value for 9*s*., paper-bound) would be worth its price for this alone.

O. M. B. B.

DIE EISEN- UND MANGANERZE DER SCHWEIZ (STRATIGRAPHIE UND PALAEONTOLOGIE DES OOLITHISCHEN EISENERZLAGERS VON HERZNACH UND SEINER UMGEBUNG). Teil I. By A. JEANNET. pp. xvi + 240 ; 107 plates. Beiträge zur Geologie der Schweiz, Geotech. Ser. Lief., xiii, Band 5. Bern, 1951. Sw. Fr. 50.

This is one of the most important monographs ever published on a European Upper Jurassic fauna. It is in the de Loriol tradition, but brought fifty years up to date.

The oolitic ironstone of Herznach, the exploitation of which has produced this wealth of ammonites, is of Callovian age, and the monograph deals also with the overburden of Oxfordian age. This first part opens with a summary of the stratigraphy and covers belemnites, nautiloids, and a part of the ammonites. The illustrations are admirable and lavish in quantity, and the text, a translation from French into German, is clear and systematic. The classification and nomenclature go beyond the last word. Almost every generic or subgeneric name ever published, whether regarded as a synonym by previous authors or not, is revived and used in full generic form. Some names are alluded to as subgenera, but all are invariably written as full genera. In addition, twenty-one new genera are introduced (of which *Rollieria* and *Bukowskites* are preoccupied).

W. J. A.

INTRODUCTION TO THEORETICAL IGNEOUS PETROLOGY. By E. E. WAHLSTROM. John Wiley and Sons (London : Chapman and Hall), 1950. pp. vii + 365, 155 figs. Price 48*s*.

This textbook for the " average student of geology ", who is assumed to have a working knowledge of petrography and at least an elementary training in physics, chemistry, and mathematics, is divided into two parts. Part I, occupying roughly the first hundred pages, treats of heterogeneous equilibrium and the phase rule, and of equilibrium in silicate systems, concluding with a rather scrappy chapter on igneous minerals. Part II has chapters on the crust and the interior of the earth ; the source, nature,

ascent, and emplacement of magmas ; crystallization of magmas ; igneous differentiation ; assimilation and syntexis ; granitization ; late magmatic and post-magmatic processes ; origin of rock types ; and finally a chapter, strangely out of place, on the classification of igneous rocks. There is an Appendix of physical-chemical concepts useful to petrologists.

According to the dust-jacket, the book is " a synthesis of the existing theories about the origin of igneous rocks—embodying the modern physico-chemical viewpoint throughout ". Actually it is a somewhat uncritical compilation of existing theories with little reference in Part II to the silicate equilibrium diagrams studied in Part I, and although a large amount of information is contained within its pages, many of the topics are treated superficially. This is partly counterbalanced by the lists of references given at the end of each chapter.

Few typographical errors were noticed, but there is something wrong with the first sentence on page 280.

S. R. N.

PRINCIPLES OF GEOLOGY. By J. GILLULY, A. C. WATERS, and A. O. WOODFORD. viii + 631 pp., with numerous figures. W. H. Freeman and Co. (Calif.), 1951. Price $5.75.

KAYSER'S ABRISS DER GEOLOGIE, vol. i. Seventh edition by R. BRINKMANN. viii + 296 pp., with 196 figs. Ferdinand Enke Verlag (Stuttgart), 1950. Price 23 Mk. (paper) or 25.80 (cloth).

There has surely never been a time so prolific in the production of geological textbooks of all kinds as the last three or four years. Whatever the motive (and increased numbers of elementary students is the principal cause) it is not altogether a bad thing ; new illustrations are sought and new presentations or methods of approach may serve to freshen the familiar field. But it can hardly be expected that any but the most exceptional will ever achieve much circulation outside the countries, and perhaps even universities of their origin. Of the two volumes cited above, one is a newcomer and the other a fresh edition of a well-established textbook.

The American text seems to take nothing for granted, and to start rather at school than university level. In scope, it is a physical geology textbook omitting any account of stratigraphy, but with this limitation (not apparent in the title) it touches on a remarkably wide field and is completely up-to-date, with a geophysical emphasis that is perhaps symptomatic of the times. It is attractively produced, clearly written if a little laboriously argued, and well illustrated : many of the figures are new to the elementary textbook range and many perform the important function of amplifying as well as explaining the text. In short, the book contains much that is not usually found in an elementary text, presented in an interesting manner ; the extended physical syllabus and the intentional avoidance of descriptive facts and terms, give it something of the superficiality of a scientific broadcast talk.

It is with a feeling almost of relief that one turns to the more orthodox. In Brinkmann's new edition (seventh) of Kayser's *Abriss der Geologie*, General Geology (part i) is clearly preparing the way for Historical Geology (part ii, revised by the same author two years ago). Geology is here interpreted in terms of the sedimentary cycle (weathering and transport, sedimentation and marine environments, and diagenesis) and the deep-seated earth processes (tectonics, igneous activity, and metamorphism) ; and is shown to have contacts with biology as well as with physics and chemistry. Here again are some good figures, but this is the more parochial of the two books and extra-european illustrations are rare.

If neither is likely to displace standard textbooks in use here, teachers may nevertheless gain ideas by browsing through either.

O. M. B. B.

A MANUAL OF THE GEOLOGY OF INDIA AND BURMA. Third edition, vol. i, revised and largely re-written by the late Sir EDWIN H. PASCOE. Delhi, Manager of Publications, 1950. xvi + 483 pages. Rs. 20 (authorized sterling price, 30*s*.).

This is the first volume of an important work which, when completed, will take first place as a standard book of reference on the geology of India and Burma. The complete *Manual* will consist of four volumes : vol. i deals with the Pre-Cambrian rocks, vol. ii with the Palaeozoic and Mesozoic, vol. iii with the Deccan Traps, the Tertiary, the Pleistocene, and Recent deposits, and vol. iv will contain geographical and general indexes.

The second edition, revised by R. D. Oldham, was published in 1893, and when the late Sir Edwin Pascoe began the work of preparing a new edition in 1933, he was faced with a formidable task. The first three volumes were ready for the printers in 1939, and more than half the book had been set up in type when Japan entered the war. Owing to the extreme shortage of paper in India at that time, it was impossible to print off even the first volume, and the type, weighing 2½ tons, was broken up and melted for munitions. Thus faced with a long delay in publication, the author once more revised the text of volumes i and ii, and was still engaged on volume iii when he was taken seriously ill in 1949.

The first two chapters give an admirable summary of the physical geography and geological history of India and Burma, which every student of regional geology could read with profit. Throughout this account the reader cannot fail to be impressed by the contrast between the rapidity of recent geological changes in the mountains and the almost ageless permanence of the main features in the peninsula. Thus we read of violent movements in the front ranges of the Himalaya during Pleistocene times, and of the probability that important river captures have taken place during historical times. In contrast with this we are told that the Aravalli range (folded and uplifted before the end of the Pre-Cambrian) " is in fact a remnant of one of the most important watersheds of Peninsular India ; it may well have been from this watershed, for instance, that some of the rivers flowed in which the rich coal deposits accumulated ".

The remaining eleven chapters are devoted to the Pre-Cambrian rocks, which are divided into two major groups, separated by a profound unconformity. The author wisely makes no attempt to extend smaller divisions to the whole of India, but describes in full detail the sequences found locally in the various parts of his territory, and then gives his opinions on their correlation. It would be futile to attempt to review the wealth of information contained in these chapters, whose value can only be appreciated when they are appealed to for reference. Nevertheless, a few subjects of outstanding interest deserve special mention. There is an excellent description of the remarkable manganiferous schists of the Dharwar System, with their valuable ore-bodies in the Central Provinces, and the discussion of the banded iron-ores also contains much of general interest, particularly in the comparison with similar rocks in the Pre-Cambrian of other continents. The author has taken great pains to present a logical and well-argued account of the post-Dharwar intrusions, and to give a strictly impartial and balanced discussion of the charnockites and their associated problems. The attempt to sort out the complicated relationships of the various masses of gneiss, both to each other and to the adjacent schists, clears away a good deal of confusion and misconception about the chronology of the pre-Purana rocks of Peninsular India.

In the absence of Cambrian fossils, it is not easy to determine the age of some of the unaltered but unfossiliferous sediments in relation to the beginning of the Palaeozoic era. There is reason for regarding the bulk of the Purana group, which includes the Cuddapah and Delhi systems, as being Pre-Palaeozoic in age, and this conclusion is supported by such evidence as is available from radioactive minerals. The Vindhyan System, on the other hand, contains rocks unlike any known before the Cambrian either in India or

elsewhere, and the author removes the Vindhyan from the Purana and refers it, with some doubt, to the earliest Palaeozoic.

In his preface the author points out that the *Manual* is to be regarded as a work of reference rather than as a students' textbook, and the treatment of the Pre-Cambrian rocks in this volume is fully in keeping with this purpose. The information is so detailed, indeed, that the book may well prove to be of considerable service to local geologists in India, as the author intended. It is pleasantly written, and notwithstanding the wealth of local detail, is far from being heavy reading ; but without its index it is by no means easy to use, and we must hope that the appearance of volume iv will not be unduly delayed. The price is extremely reasonable when compared with that of books of a similar calibre which have been published recently. It is perhaps a pity that a work of such scholarship and distinction, destined to face many years of constant use, could not have been given a more attractive format and a more robust binding ; most of the copies seen by the reviewer had already suffered damage before reaching their destination in this country. But these are trifling matters : it is a cause of great satisfaction that Sir Edwin Pascoe's edition of the *Manual* is at last being published. For many years to come it will remain as a fitting memorial not only to the author himself, but also to the whole staff of the Geological Survey of India, with their long record of devoted service and distinguished achievement during the period which has now come to an end.

M. B.

SILICATE ANALYSIS. By A. W. GROVES. George Allen and Unwin, Ltd., 1951. pp. xxiii + 336, 11 figs. Price 25*s*.

The second edition of this well-known and useful book has been considerably revised and improved. While the author keeps, for the most part, to the well-tried methods given in the previous edition, he is careful to point out improvements or alternative methods which have been devised during the past twelve years. In the chapter on Normal Methods for Silicate Rocks more attention is given to methods of determining ferrous iron, lithium, chromium, and vanadium, while new sections on phosphate rocks and on the determination of free and combined silica appear in the Notes on Technological Applications. The chapter on Special Methods has much enlarged sections on determination of ferrous iron in refractory silicates, and of manganese, with new sections on the direct determination of sodium or potassium, the determination of minute quantities of nickel, and on micro- and semi-micro- methods of analysis. It is a pity that no mention is made of the polarograph or of the flame photometer as these are likely to be increasingly used in silicate analysis in the future. The chapter on Errors is enlarged and made more valuable, and the final chapters on Occurrence of the Various Elements and on Computations as a Check on the Accuracy of Chemical Analyses have been virtually rewritten. Incidentally, the statement on page 258 that Al occurs surrounded by four oxygens in the structures of minerals is very misleading.

In calculating the structural formulae of minerals, the author advocates the use of molecular weights to two places of decimals and five-figure logarithms, so that the results are accurate to three places of decimals. It is doubtful if the average chemical analysis of a mineral is of a high enough degree of accuracy to give a structural formula accurate to more than two places of decimals. Errors occur in the valency checks given in Tables X (p. 314) and XI (p. 316). In Table X, Si^{+4} should be 7·868, Al^{+3} should be 0·240, Li is shown with two positive charges. In Table XI, Al^{+3} should be 8·292, Ti^{+4} should be 0·356, Mg^{+2} should be 6·216, and Mn^{+2} should be 0·030. The author points out that the kind of valency check used by him is no check on the accuracy of the chemical analysis of a mineral. But valency checks balancing excess negative charges caused by substitution of metal ions of lower valency than that proper to a group, with excess positive

charges caused by substitution of ions of higher valency than that proper to a group, do give a valuable check on the accuracy of the chemical analysis in many cases.

There is an error in Appendix B, which appears also in the first edition. SiO_2 is stated as 51·44 per cent, opposite a determination of SiO_2 which gives a value of 51·14 per cent. Presumably the first figure includes the amount found in the blank for HF, given later, but the final value for SiO_2, given in Appendix C, is 51·47 per cent.

S. R. N.

PETROLEUM GEOLOGY. By KENNETH K. LANDES. John Wiley and Sons (Chapman and Hall), 1951. pp. xi + 661, with 222 text maps and diagrams. Price 50*s*.

The great increase in scope of the profession of Petroleum Geologist during the past twenty-five years, and the large increase in the number of those employed in the oil industry who require some knowledge of the subject, must lead to up-to-date textbooks. A recent number of the *Geological Magazine* included a notice of Dr. Tiratsoo's *Petroleum Geology*, the first new British textbook. In 1949 two new books appeared in America, Professor Lalicker's convenient summary, *Principles of Petroleum Geology* (377 pp.), and Le Roy's and Crain's symposium on *Subsurface Geologic Methods*, 826 pp. (to which thirty-nine authors contributed). Now we have another general textbook, by Professor Landes, who has carried out his task in a thoroughly professional fashion, in both text and illustrations. Following an introductory chapter on " The Profession " (19 pages) the book devotes 120 pp. to techniques (exploration 75 pp., exploitation 23 pp.) ; properties, origin, migration, and accumulation of oil, 201 pp. ; a brief description of American oilfields State by State, 183 pp. ; a briefer description of the oilfields of the rest of the world, 89 pp. ; and future supplies, 32 pp. The technique, origin, and accumulation part of Professor Landes's book will certainly admirably fulfill the purpose for which it was written : " to aid the student whether he is in the classroom or on the job." The most useful descriptions of oilfields for the general student are those used as illustrations in the chapter on accumulation traps (117 pp.). Lalicker in his much smaller book omitted brief descriptions of the world's oilfields on a geographical basis. In view of the large proportion, about 40 per cent, of Landes's book devoted to this type of description, which is too short for serious reference purposes and too long to form a catalogue, one wonders whether such omission is not the best plan for general use, because it would allow considerable expansion of other subjects without making too large a volume ; " The Oilfields of the World " is a large enough subject for a reference book on its own (*World Geography of Petroleum*, by Wallace E. Pratt and Dorothy Good, 1950, is written from a geographer's standpoint, not a geologist's). However, obviously Professor Landes thinks otherwise. Certainly his American descriptive section, with its excellent maps, gives a vivid impression of the vast number of American oilfields. These have been discovered by the drilling of hundreds of thousands of test wells, for many reasons, including geological. The moral surely is that oil seekers in other lands must not be inhibited, by the growing weight of science at their disposal, from speculative drilling. Recent discoveries have shown that even a freshwater environment may not be unfavourable for oil formation. A few exceptions do not, of course, disprove a general rule with a considerable volume of factual support, but this example shows how a theory too slavishly followed may restrict discovery. The book is well printed and liberally supplied with references (mostly American).

N. L. F.

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